MONTHLY NOTEBOOK

Science on Television

Canada's Heavy-Water Pile

Scientific and Technological Uses of Photography

TITANIUM

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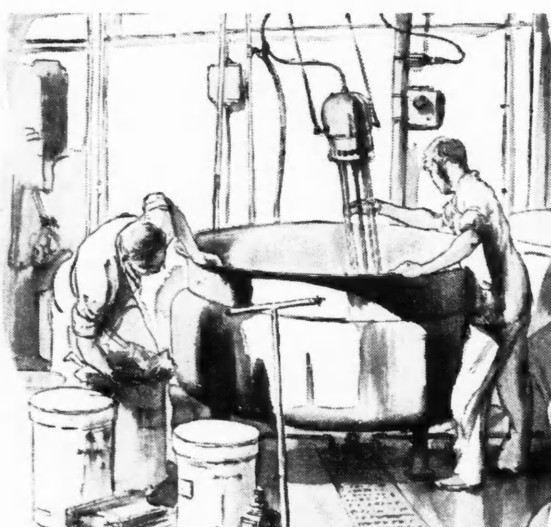

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THE MAGAZINE OF SCIENTIFIC PROGRESS

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APRIL 1953 VOLUME XIV NUMBER 4

THE PROGRESS OF SCIENCE

SCIENCE ON TELEVISION

When the first televised pictures made their entry into British homes, several leading scientists prophesied that the new medium of entertainment could become an ideal medium for the dissemination of science to the millions. Looking back, that surmise appears to have been fulfilled, at least partially, for much scientific, or near-scientific, material is now televised from the Lime Grove Studios at Shepherds Bush.

It is estimated that about four million people are regular viewers of the monthly *Science Review*. This twenty-minute programme consists of excerpts from and condensed versions of films produced by industrial companies, universities, university research laboratories and other organisations, and in addition it includes special films shot by Norman Macqueen, a B.B.C. staff man who is making quite a name for himself as a scientific film director. The series of stimulating programmes entitled "Matters of Medicine" has introduced the British public to the physiological effects of nicotine, alcohol and burns, and to their social and medical aspects; each subject is treated in an interesting way, which reflects credit upon its script-writers and producers, as does the high standard of scientific accuracy they maintain.

In recent months viewers have also been introduced to the physiological considerations involved when the human body is subjected to extremes of cold and heat, and to abnormally high and low pressures. These programmes, made with the collaboration of Service personnel, have more than held their own, for sheer interest, with the programmes of so-called 'light' entertainment with which they have to compete for studio time.

Another recent scientific programme of note was that in which Professor Andrade showed viewers the elements of electricity and magnetism that have affected the lives of everyone through their industrial application.

Many other recent programmes can be classed as scientific, using that term in its broadest sense for that wide category of programmes which touch upon matters with some scientific or technological interest. "Inventors Club", in which inventors present new gadgets intended for multifarious purposes, falls within this classification. Here also belong the programmes in which George Cansdale has been demonstrating, with live examples, the adaptation of various organs, such as the tail and eye, so that they perform special functions related to the special conditions under which particular animals live. Viewers have also recently witnessed a phrenologist and a professor engage in a discussion about the shape and form of a human brain, and the effects thereof on the affections and general social behaviour of the owner. If this particular programme was no more than 50% scientific, it was certainly amusing.

At present amusement or entertainment value is, in fact, the only yard-stick by which the suitability of scientists, or their work, can be judged for television. This means that a great deal of science is ignored by television producers because it is of the type which intrigues no one except the particular specialist scientists, and which does not lend itself to popular treatment at all. If a scientist is to make his mark on television, he must be able to produce material that can bear comparison with the slickest of TV theatrical productions. Otherwise, the promise that television may become the perfect medium for the general dissemination of science must remain a long way short of realisation. This is quite apart from the fact that many science subjects which lend themselves to visual presentation are unsuitable for popular treatment, and are therefore beyond the reach of television unless the B.B.C. starts up TV programmes putting across material at a level comparable to that of Third Programme radio features. There are besides certain scientific subjects which are unsuitable for television because they cannot be put across visually.

Nevertheless, the British public is avidly interested in what scientists are doing. A high proportion of people are just as curious about science as is the proverbial schoolboy, and when B.B.C. television makes room for science on the air it is only responding to a public demand that is insistent and growing. To do their job well, however, the

television producers need the assistance of scientists whose ideas about the presentation of scientific material are not too rigidly fixed, and who are prepared to learn all the subtleties and pitfalls of the new technique from the professionals at the studio. It is unfortunately true that some scientists take little or no trouble to make their material interesting, a fault which spoils all types of lecture, and especially the popular lecture. This type of lecturer can fail to put his subject across because his exposition is not lucid, or because he rambles from one aspect of the subject to another, leaving behind him a muddled miscellany of half-remembered facts which cannot benefit his audience. Some lecturers cannot divest their utterances from unnecessary scientific jargon, and they, too, strive quite unavailingly to get their message across. Their material, which might be appreciated by a group of university students prepared to meet their lecturers more than half-way, goes right over the head of the wife of a motor engineer in Slough who, while she looks and listens, is also giving some of her attention to her knitting. The scientist who wants to be effective in a television programme has to remember that this kind of viewer is a typical member of the large but scattered audience he has to impress.

Besides the difficulties of expression and interpretation—and since no questions can be asked at the conclusion of the televised lecture every point must be decisively made at the moment of speaking or demonstration—there are psychological difficulties which the TV performer has to consider. For example, the speaker has nothing to look at except the large round eye of the camera. He cannot scrutinise the audience to see whether it is following and appreciating his words or the experiment he is performing. He cannot see his audience and take courage from their response. At best the eye of the camera is inscrutable, and many a prepossessed speaker has admitted that he has felt his blood turn to water as he confronted it. In front of the camera the man who is an excellent demonstrator at home in his laboratory may put up an indifferent show, and the indifferent demonstrator may prove unspeakably bad on television, getting himself tied up with his apparatus until he, and his assistant, look like nothing so much as Laocoon and sons in the last stages of their struggle with the serpent.

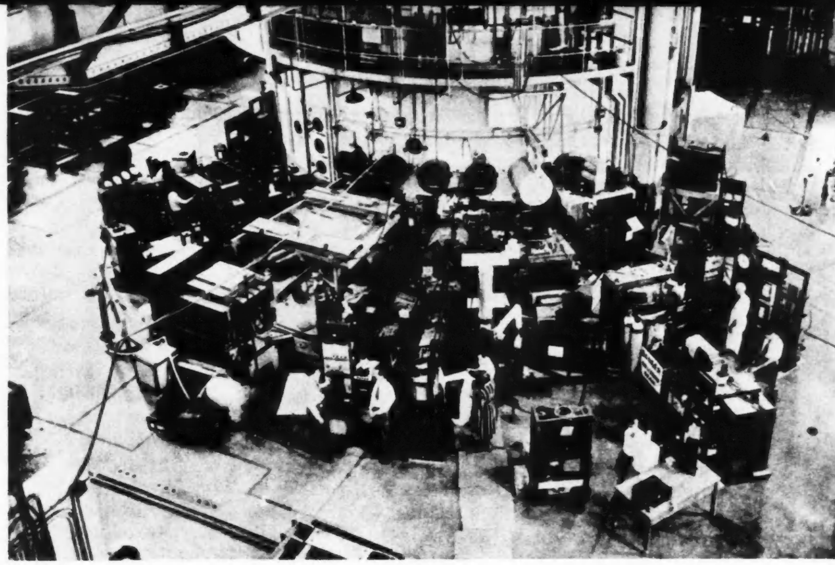
Despite all the hazards, some of our leading scientists have done, and are doing, extremely well before the camera. Professor Andrade, after a slightly doubtful start, settled down quite comfortably in the recent "From Small Beginnings" programme and evidently has learned to make good use of the television medium. Professor Huxley's smooth style and careful diction have also established his television reputation. One of the scientists who have been most successful on television is Dr. Bronowski, who always appears to be completely at home in front of the camera, so that the millions of his unseen audience are put at their ease and are consequently more receptive to the facts presented to them. Moreover, he has been without a television rival in that important matter of explaining the philosophical and economic import of the scientific developments of which he is speaking.

It is already clear that not all the sciences provide equally good material for television. As a whole biology has proved far and away the best suited to this kind of presentation, and has been prominently featured by TV producers because of this, and because such aspects of plant and animal life as growth and movement are of perennial interest to ordinary persons of all ages. High on the list comes physics, but by comparison chemistry seems to be less satisfactory. There is something rather static about chemistry on television; even simple things like precipitations are extremely difficult to show under the fixed lighting to which television is bound.

Certain scientific matters (e.g. experiments on living animals involving vivisection) are practically banned so far as B.B.C. television is concerned, though many may regret that it is not possible to have a single TV programme to

Prof. Andrade (*left*) and Dr. Bronowski, two of the scientists who have made their mark on television.

The NRX pile has given valuable service as a research tool, and it has also provided data required by nuclear engineers for the designing of new piles, such as the NRU Canadian heavy-water pile due to be completed next year. (*Photo by courtesy, Atomic Energy of Canada Ltd.*)



explain the importance of the subject just mentioned to the layman. Nevertheless, a number of somewhat delicate subjects, such as artificial insemination, have been graphically described and portrayed on television without, so far as is known, any protest—even of the mildest—from the vast and variegated audience. Here the producers have evidently shown a remarkable intuitive judgment of the sensibilities of their audience.

The producer of scientific programmes has no easy furrow to plough. As we have said, most scientists are not very communicative when they have to explain things in non-technical terms. This can be rectified so far as television is concerned if the scientist takes full advantage of his producers' and script-writers' experience in the technique of exposition. If the tail—the scientist—wags the dog—the producer—a great disservice can be done to the cause of televised science. But if the scientist is prepared to be adaptable, if he will accept rehearsal after rehearsal of his talk and his demonstrations, until a smooth, simple and intelligible whole is achieved, and if he will remember that conventional lecture-room manner is totally unsuited if he is to interest that harassed little housewife in Slough, then we can look forward to a considerable progress in the dissemination of science by television.

CANADA'S HEAVY-WATER PILE

In specialist circles the Canadian heavy-water pile known as the NRX pile is deservedly famous. But most people were unaware of its existence until very recently when the reactor came into the news because it had to be shut down. This action had to be taken when a serious leak of radioactive particles from the pile occurred, and the pile could not start operating again until an extensive job of decontamination had been done, which took several weeks.

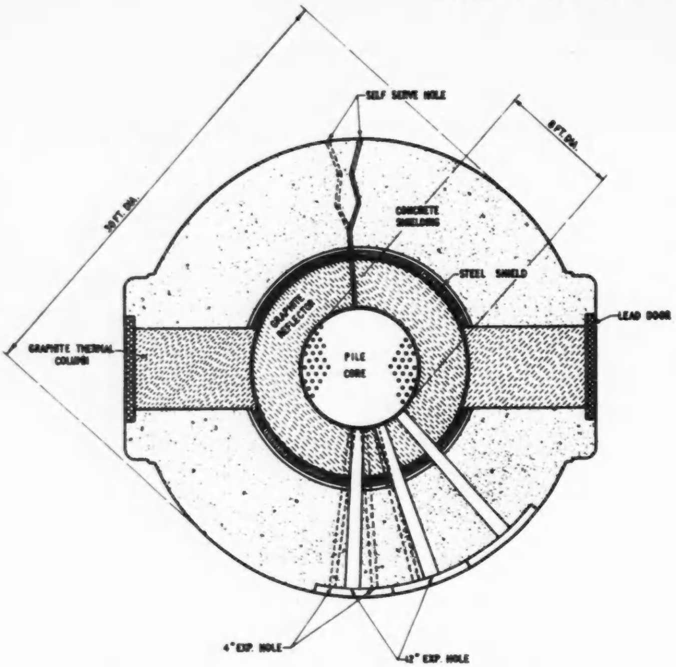
From the technical point of view the reactor is very interesting indeed, and this was conveyed by Sir John Cockcroft's remark, made last year, that it was "far and away the best in the world and likely to be for several years to come".

Situated at the Canadian atomic research station at Chalk River, 125 miles west-north-west of Ottawa, the NRX reactor has made possible a whole range of investigations in atomic energy and nuclear physics, impossible elsewhere. Originally the Chalk River centre was a unit of the National Research Council, but is now controlled by Atomic Energy of Canada Ltd., the Crown Corporation responsible for atomic energy development.

In reactors using natural uranium the fast neutrons produced by the fission of the uranium 235 nucleus have to be slowed down to thermal energies to increase their chances of causing the fission of other uranium 235 nuclei, and the slowing-down process is achieved by the use of a 'moderating' material. In all existing reactors, the moderator is either graphite or heavy water. The American and British projects, with their emphasis on military uses, have concentrated on graphite-moderated reactors, which are most productive of plutonium. Canada, on the other hand, has been concerned with developing heavy-water reactors. The first, a low-power reactor known as ZEEP, gave the experience necessary for the construction of the second heavy-water reactor, the NRX pile. The great advantage of using heavy water as the moderator instead of graphite is that it makes possible a smaller and more compact pile, and this means a pile with a higher neutron flux for a given power. The NRX pile, which was designed with power rating of 10 megawatts, has a maximum neutron flux of 6×10^{13} neutrons/sq. cm./second, *which is ten to twenty times the flux in a graphite reactor of comparable size.*

The NRX pile consists of a cylindrical vessel, eight feet in diameter and ten feet high. This holds the heavy water, and through it pass vertical tubes containing a total of 176 uranium metal rods, which are kept cool by water from the Ottawa River. The central vessel is surrounded by a belt of graphite, whose purpose is to reflect escaping neutrons back into the core. Around the graphite belt is first a steel shield, and then a thicker shield of concrete; their purpose is to absorb escaping neutrons and gamma radiation, so that the human operators can carry out their work without danger. The overall diameter of the pile is thirty feet.

Control of the reactor is simple. The chain reaction is



Schematic plan of working section of NRX pile. Note in lower part of diagram the holes used for experiments involving long irradiations, and for letting beams of neutrons or gamma-rays through the shield.

started by pumping heavy water into the reactor vessel until a certain critical depth is exceeded. The power proceeds to build up, and when it reaches the required level the depth of the heavy water is adjusted until the power stays constant. For fine adjustment there is a cadmium rod to absorb excess neutrons. Once the pile is running steadily, control is automatic, the movement of the cadmium rod being actuated by current from a suitably placed neutron-sensitive ionisation-chamber. The power can thus be kept to within ½% of a fixed figure. Should anything go wrong, neutron-absorbing rods, known as shut-off rods, can be projected into the core by compressed air.

There are various arrangements for irradiation of different kinds of material with neutrons produced by the pile. Substances which require a high neutron flux, such as cobalt, are irradiated within the pile's core, and they make heavy demands on the neutron population which is maintained there. Many radio-isotopes, how ever, can be produced in sufficient quantity by using the neutrons which escape from the core, and for this purpose 'self-serve' arrangements exist which allow samples for irradiation to be introduced, through the shielding and the graphite reflector, to the core vessel face; this procedure is carried out without shutting down the pile, as is the withdrawal of the specimens after irradiation.

For experiments requiring collimated beams of neutrons or gamma rays, six holes penetrate the shielding right through to the core. The pile is also designed for experiments with neutrons of thermal energies; for this purpose the graphite of the reflector has been continued in two columns through the steel and concrete shielding.

The neutron flux available in the NRX pile is believed to be the highest attained in any nuclear reactor, and has proved invaluable for studying the effects of neutron bombardment on the various different kinds of materials used in constructing piles. The design of American and British reactors owes much to the information about this and other makers gained by use of the NRX pile.

This very high neutron flux has made possible the commercial production of radioactive material in unrivalled concentrations—for example, cobalt 60, which is produced by neutron irradiation of ordinary cobalt, and which is used as a substitute for radium in therapy and radiography, because of its emission of penetrating gamma rays. It takes eighteen months' irradiation in the high flux of the NRX pile to produce radio-cobalt samples with a specific activity of thirty-five curies per gramme. Pieces of irradiated cobalt, which have an effective strength of 1000 curies a piece, have been made for Canadian hospitals and used in cancer therapy.

That heavy-water reactors have an important part to play in the development of atomic energy is clear from this brief account of the indispensable role which one particular reactor has played, to which must be added the fact that the Canadians are building a bigger and better pile of this type (known as the NRU pile), and that a British heavy-water pile has been started at Harwell (as was reported in our last issue).

SCIENTIFIC AND TECHNOLOGICAL USES OF PHOTOGRAPHY

To describe the uses of photography in science and technology is like trying to describe the uses of eggs in cookery—they are almost unlimited in number and variety. It all depends on the inventiveness and ingenuity of the user. A great deal of scientific photography is merely a superior form of snapshoting, that is, the making of permanent pictorial records of events. Whereas the traditional users of photography rarely depart from record-making, scientists on the other hand often use photographic processes for measurement or for detecting phenomena which are not easily observed in other ways. Photography has become a tool of research, and typical examples of its use can be found in most of the fields of investigation which are being actively studied.

In the testing of aircraft there is often no room for a human observer apart from the pilot, and if there were, he would not be able to make accurate notes of the readings of all of the instruments in the cockpit during a test flight. It has therefore become routine practice to install a cine-camera to photograph the instrument panel during test

flights. The results so obtained on sub-standard cine film can then be analysed at leisure later on the ground. If by misfortune the flight ends in disaster, there is a chance that the camera may be retrieved and its record may be the means of preventing a recurrence of the accident. Much of the data collected by the scientists engaged on guided missile projects has come from the photographic records taken by automatic cameras carried by the rockets on their experimental flights.

The behaviour of shells and other projectiles in flight is another subject which demands photographic observation, since so little can be learnt from direct visual observation. Photographs can be taken with exposures lasting only about a millionth of a second, and this effectively 'stops' most fast-moving objects and makes it possible to obtain snapshots which show quite clearly those details which interest the technical experts. Moreover, the picture may also reveal such transient phenomena as shock waves and turbulence in the air around the fast-moving body. These disturbances would be very difficult to detect in any other way, and their study does indeed depend very largely upon photography.

New and more powerful telescopes have been much in the news recently. Astronomers have long relied upon photographic observation, but probably it is still not generally realised that modern telescopes are not intended for looking through but are designed to give pictures of the heavens which are permanently recorded on photographic plates. The photographs so obtained have largely replaced the direct visual observation upon which the early astronomers had to depend. To the pioneers of astronomy the most distant stars were unknown because they were invisible, being so faint that they could only be discovered by systematic photography of the sky, using long exposures. Even in the case of those stars which were directly visible to the astronomer looking through his telescope there was still much additional information to be gained when different photographic techniques could be brought to bear. For example, the light from a star can be analysed spectrographically, and from the photographs of the spectra of stars information is obtained about their chemical composition. A discovery of profound theoretical importance was made by studying star spectrograms, namely, that the farther away from the earth a star is, the more rapidly it appears to be receding from the earth. This most important phenomenon, which could hardly have been made without the help of photography, has to be taken into account by anyone who aims to produce a theory explaining the creation of the universe.

Developments in the field of atomic physics have involved a number of new uses for photography. One particularly interesting example, although far removed from conventional photography, is basically an orthodox use of photographic material. The well-known Wilson cloud chamber is an elegant means for studying the behaviour of fundamental particles, but this delicate apparatus is not very convenient for use outside the laboratory and in addition it gives only transient records of the tracks of particles, which require to be photographed before one has permanent records which can be consulted at any time in the future. There is a new technique in which a photographic emulsion is used almost as though it were a cloud chamber. In this method it is arranged that nuclear reactions take place in the body of the emulsion on a photographic plate. Just as a charged particle betrays its path through the cloud chamber by a trail of water droplets, so it leaves behind a track in the photographic emulsion which becomes a visible track when the plate is developed. In this case the trail of the particle is a permanent record which can be studied at any time. This fascinating technique and the valuable results which it has yielded have been of such great scientific importance that they were recognised by the award of a Nobel Prize in 1950 to Professor C. F. Powell of Bristol, who did pioneering work with his method. Recently cosmic ray research has been carried on over a hundred miles above the earth by this means, photographic emulsion preserving the record of bombardment by cosmic rays which it encountered as it was carried aloft by rockets.

The earliest photographic materials were only sensitive to light at the blue end of the spectrum, but the discovery that silver bromide emulsions could be made sensitive to light of other colours by means of dyes resulted in materials becoming available which were practically uniformly sensitive to light of any colour. By this means films have also been made which are sensitive to infra-red radiation, and these find limited use for special purposes. Infra-red radiation is scattered to a smaller extent than visible light when it strikes opaque particles, and thus it has the power to penetrate such things as mist, thin layers of skin and thin coats of paint. Infra-red sensitive films are used for aerial photography when it is necessary to penetrate haze. In medical research such films can give information about skin conditions, and infra-red photographs of old paintings have frequently revealed detail invisible in light of shorter wavelengths.

For the preparation of maps of all kinds, aerial photography is now widely used. World War II saw a revival of interest in stereophotography for aerial reconnaissance and in particular for aerial assessment of the results of bombing. This technique, which is no novelty, and seems to have been a favourite of Victorian photographers, has been developed as a means of preparing contoured maps. From stereoscopic pairs of aerial photographs an elaborate machine traces a master map on which are drawn the contour lines. In this way, not only can old maps be corrected, but maps of new territory can be prepared in a fraction of the time and at much lower cost than would be the case if a ground survey had to be made.

Whatever the use of photography is, its basis is almost invariably the formation of a latent image in a silver halide emulsion. This process has not undergone any fundamental change since it was first discovered, and there is no sign at present that any other kind of photochemical process can take its place. The materials which are available for scientific photography increase in variety from year to year, and as a result the use which scientists make of photography increases in extent and variety every year.

The importance of the scientific and technological applications of photography was well brought out by Mr. I. D. Wratten, who is the president of the Royal Photographic Society, in his lecture to the Royal Society of Arts on February 4. This is the centenary year of the R.P.S., and

Continued on p. 112

FIG. 1. A batch of titanium sponge from the pilot plant. This material is tough and has to be chipped or cut out of the container.

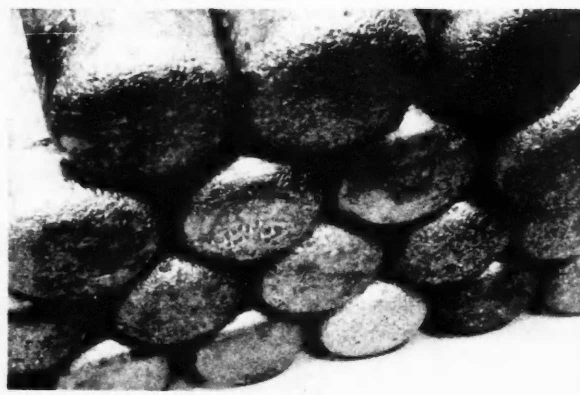


FIG. 2. A pile of titanium ingots.

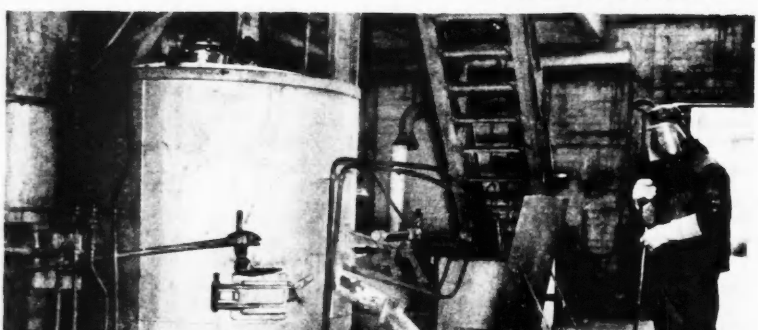


FIG. 3. Tapping molten magnesium chloride from the reactor during the reduction of titanium tetrachloride.

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TITANIUM

S. W. ROWELL and **E. SWAINSON**
B.A., D.Phil. B.Met.

For about a century after its isolation the metal titanium remained a laboratory curiosity, and scarcely more than a thousand tons of it have been made altogether in the years since its discovery in 1790. Less than 20 years ago the first useful titanium alloy was made. But a new era has now opened with the development of processes for producing high-purity titanium in considerable quantities. The exploitation of the unusual properties of titanium and its alloys is gaining momentum, and engineers in many fields are intensely interested in the possibilities which titanium offers in connexion with special problems. The metal already finds substantial use in the manufacture of gas-turbine engines for aircraft.

Among the most important metallurgical achievements of recent years has been the development of methods of producing titanium on a commercial scale. Titanium metal has desirable qualities, being strong, light and resistant to corrosion, and its ores are widely distributed, but difficulties in extraction and fabrication have held up its engineering application for over a hundred years.

Titanium was discovered in 1790 as a constituent of a black magnetic sand found near Falmouth in Cornwall. It was isolated, in a very impure form, by Berzelius in 1825, and because of the extreme stability of titanium compounds, metal of more than 99% purity was not obtained until 1910. The metal then produced could be forged at red heat, but in the cold, it was hard and brittle and generally unpromising as a constructional material. However, subsequent experiments suggested that brittleness might not be an intrinsic property of the metal but was perhaps caused by the small amounts of impurities. This supposition was not finally confirmed until 1925, when two Dutch workers, van Arkel and de Boer, made a very small amount of substantially pure titanium which proved to be quite soft and malleable. Their method was to decompose titanium tetraiodide vapour on an electrically heated filament in the absence of air and, although this technique has not yet proved suitable for the large-scale production of titanium, it is still employed for making small amounts of high-purity metal required for research purposes.

The knowledge that pure titanium might be a valuable engineering material stimulated further experiments on its production, but it was only in 1940 that a process with commercial possibilities was reported. In this process, developed by Dr. W. J. Kroll, titanium tetrachloride is reduced to metal by molten magnesium, and this is carried out in an atmosphere of the inert gas, argon, to prevent the titanium so produced from being contaminated. The Kroll process was taken up by the U.S. Bureau of Mines, and by 1946 had been made suitable for small-scale industrial operation. With minor modifications it is essentially the method at present used for bulk production of titanium in the U.S.A. It has also been employed in a pilot plant at Widnes, put in operation by the I.C.I. (General Chemicals Division) two years ago, and will be used for larger-scale production there next year.

In the light of our present knowledge, it is not difficult to understand why many of the early processes proposed for the production of pure titanium met with little success. Titanium is extremely reactive and can be separated from its compounds only by very strong reducing agents, while, at elevated temperatures, it combines rapidly with atmospheric gases. In many of these respects it is not unlike other metals of high melting point, but the peculiar characteristic of titanium which makes its production so difficult is that oxygen, nitrogen and hydrogen actually dissolve in the solid metal. The solid solutions so formed have mechanical properties very different from those of pure titanium, and with quite small concentrations of such impurities the metal becomes brittle and unworkable. To produce ductile titanium, therefore, it is necessary to exclude all but the last traces of oxygen, nitrogen and hydrogen. This means that the reduction processes must be carried out in the complete absence of air, and it also means, in practice, that titanium oxides cannot be reduced to metal directly because the amount of oxygen dissolved in the titanium produced in this way is sufficient to make the metal brittle. This difficulty is overcome by converting titanium dioxide into titanium tetrachloride and reducing this with magnesium. In the Kroll process, the other problems are solved by the use of a high vacuum or inert gas to protect the hot metal, and by carrying out the reduction well below the melting point of titanium, which minimises the risk of contamination from the reaction chamber.

THE KROLL PROCESS

The first step in making raw titanium by the Kroll process is to obtain pure magnesium and titanium tetrachloride. Ingots of magnesium produced electrolytically or refined by distillation are suitable, provided that their surfaces are cleaned immediately before use; scrap or secondary magnesium is not satisfactory. Titanium tetrachloride is at present made by heating briquettes of titanium dioxide and coke in a stream of chlorine, but methods involving direct chlorination of titanium ores are receiving considerable attention. The tetrachloride is a pale, oily liquid which boils at 137° C. It has a great affinity for water, so precautions have to be taken to keep moisture away from it. Even then it is best to redistil the liquid immediately before use.

In the Kroll process as practised at present the reactor in which reduction is carried out is usually a cylindrical steel vessel having a run-off point at the bottom. The reactor is charged with magnesium ingots, and then sealed to make it air-tight. Air in the vessel is displaced by argon, and the reactor is then heated in a gas-fired furnace usually to about 800° C, a temperature above the melting point of magnesium. The reaction is started by feeding titanium tetrachloride liquid into the reactor through a tube in the lid. As the chloride is reduced to metal, heat is generated, and the external furnace is controlled to maintain a steady temperature in the reactor. The feed of titanium tetrachloride continues for several hours, and during the reaction, magnesium chloride formed as a by-product is tapped off. (This magnesium chloride can be returned to the magnesium cells, where electrolysis recovers the magnesium.)

When this stage in the process ends, the reactor contains titanium, magnesium chloride and any surplus magnesium. In the original Kroll process the titanium was separated from this mixture by dissolving the by-products in water and dilute acid, but the metal remaining was found to have picked up some oxygen and hydrogen.

Present practice is to purify by vacuum distillation, when a softer hydrogen-free product is obtained. To do this, the reactor is cooled and, after removing the lid, it is inverted at the top of a long cylindrical retort. Below the reactor is placed a perforated coned grid and below this a receiver. The retort is evacuated to a very low pressure (1 micron) and heated to about 1000° C.* The magnesium and magnesium chloride distil off the reaction product, so that when the retort is opened (after it has cooled) it is found to contain only a sponge-like mass of titanium. This is chipped out, crushed and tested in preparation for further processing.

The Kroll process gives rise to many difficulties in design and operation and for this reason is regarded by many people as likely to be superseded. The difficulties increase with the size of plant and indeed the first units were capable of making only 200-lb. batches. The new I.C.I. plant will produce much larger amounts, as will new American plant that has been laid down. Nevertheless the cost of raw materials, argon, high-temperature and high-vacuum equipment is high, and the process cannot be other than expensive. It is not surprising, therefore, that in America titanium sponge still costs five dollars a lb. In the authors' view, it is unlikely that very great reductions in cost can be made by improvement of the Kroll process, for the problems of heat transfer appear to fix an upper limit to the size of batch produced and great difficulties are involved in adapting the process to continuous operation. Another factor makes it expensive; although theoretically the by-product magnesium chloride could be electrolysed to yield all the magnesium and chlorine for further processing, in actual fact it proves necessary to supply large amounts of magnesia and chlorine to make up for the loss of those two elements which occur in practice. Published figures suggest that the amounts of chlorine, magnesium and titanium tetrachloride which are required for the production of titanium sponge, inevitably mean a high capital investment.

* Special measures are necessary to maintain this pressure and temperature, including the evacuation of the furnace itself to stop the retort collapsing, and the use of water-cooled vacuum joints.

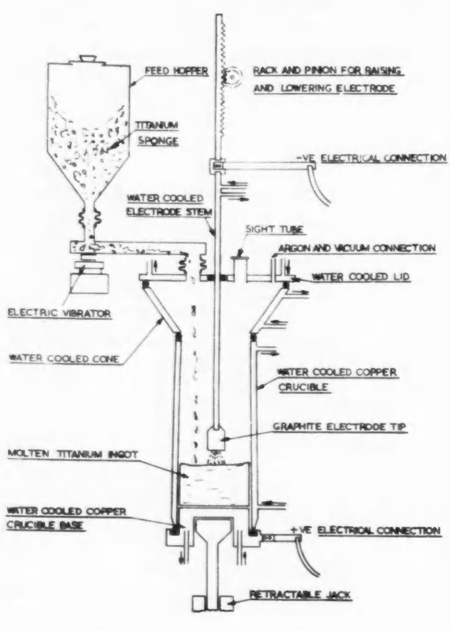

FIG. 4. Line diagram of milling furnace.

Having produced titanium sponge, the next stage is to melt it into ingot form suitable for further fabrication. Here again difficulties arise, for the melting point of titanium is approximately 200° C above that of steel, and at this temperature titanium not only combines with oxygen and nitrogen in the furnace atmosphere, but it also attacks and dissolves all known furnace refractories. This behaviour makes it necessary to employ a most unusual melting technique, in which the furnace crucible is maintained at a considerably lower temperature than the molten metal which it contains! So that the crucible can be effectively cooled, it has to be made from a material of high thermal conductivity. For this reason copper has proved most suitable, for although the melting point of copper is 700° C below that of titanium, a copper crucible can be so well cooled by water flowing over its walls that a large pool of molten titanium can be maintained inside it without the temperature of the inner face of the crucible exceeding even 100° C. With a cooled crucible, heat losses are so great that a large amount of energy must be generated within the furnace, and this is provided by an electric arc struck directly from a cooled negative electrode on to the metal charge.

A laboratory furnace designed on these principles was first employed to melt small buttons of tantalum as early as 1905, and was applied to titanium manufacture by Kroll in 1940. Since then furnaces have been developed in the U.S.A. and by I.C.I. (Metals Division) to melt cylindrical ingots of up to several hundred pounds weight. The crucible employed in melting such an ingot is essentially a cooled copper tube, the lower end of which is closed by a separately cooled base plate. First, a small initial charge of crushed titanium sponge is placed on the base plate and melted, in an argon atmosphere, by an arc struck between it and a cooled negative electrode. Further quantities of sponge are then added continuously or intermittently to the original molten pool and as they are melted the electrode is withdrawn vertically so that an ingot is built up in the crucible. When a predetermined weight of charge has been melted, the arc is broken and, after a short cooling period, the ingot is extracted from the crucible by withdrawing the base plate. In a refinement of the process, the base plate is slowly lowered during actual melting, so that the ingot is extracted continuously.

This type of furnace of course differs radically from those employed for melting steel, copper, aluminium and the

other common engineering metals, although it is now also being used for melting molybdenum and zirconium. From the operators' point of view it has one important advantage over more normal furnaces, in that it is possible to control the course of melting while standing less than a foot away from the molten ingot without becoming uncomfortably hot. Naturally, at the present early stage of development, the furnace has also many disadvantages, but nevertheless there seems little doubt that it will remain the standard method of melting titanium for some years to come. A likely development is a furnace in which the negative electrode is pressed from titanium sponge and is continuously consumed during melting.

PROPERTIES

Once titanium has been cast into ingot form most of the major troubles are over. It can be hot worked without severe contamination from gases at temperatures between 800 and 1000° C by the conventional methods of forging, rolling and extrusion. Cold working is more difficult, for heavy loads are required and titanium tends to seize on tools and dies, but such normal wrought forms as rod, plate, forgings, wire, sheet and tube can be made. From an economic point of view it is important to minimise the amount of titanium scrap made during processing, as this cannot be recycled owing to contamination of the surface with oxide and difficulties in melting. It is therefore almost completely wasted.

Titanium is somewhat less easy to machine than stainless steel; it can be welded by spot, seam, butt, flash and modified argon arc techniques, and cut by an oxy-acetylene torch. It cannot at present be satisfactorily soldered, brazed, anodised, electroplated or electro-polished.

Despite its high reactivity and affinity for oxygen at elevated temperatures, massive titanium is extremely stable at normal temperature. It owes this property to the instantaneous formation of a protective surface film of oxide on exposure to air; in general only those agents which destroy or penetrate this film are corrosive to titanium, and oxidising agents which tend to reinforce the film do not attack the metal. In this characteristic, and in general resistance to corrosion, titanium resembles stainless steel, but it is superior in withstanding the attack of chloride and acid chloride solutions, including sea water. Under marine conditions, in fact, the resistance of titanium is equal to that of the platinum group of metals and is very much greater than that of any of the alloys at present employed. Titanium has the remarkable property of being completely unaffected by aqua regia; it is, however, rapidly attacked by dilute hydrofluoric acid, the fluorine ion penetrating the oxide film.

It has already been mentioned that the hardness, malleability and other mechanical properties of titanium are to a large extent dependent on purity, particularly on oxygen and nitrogen content. This very pure metal made by the van Arkel process will withstand a tensile stress of approximately 14 tons per square inch of section before fracture, and is elongated by about 50% before final rupture occurs. By contrast, commercial titanium made by the Kroll process has a tensile strength of about 50 tons per square inch, with only 20% elongation. Less pure metal has an even

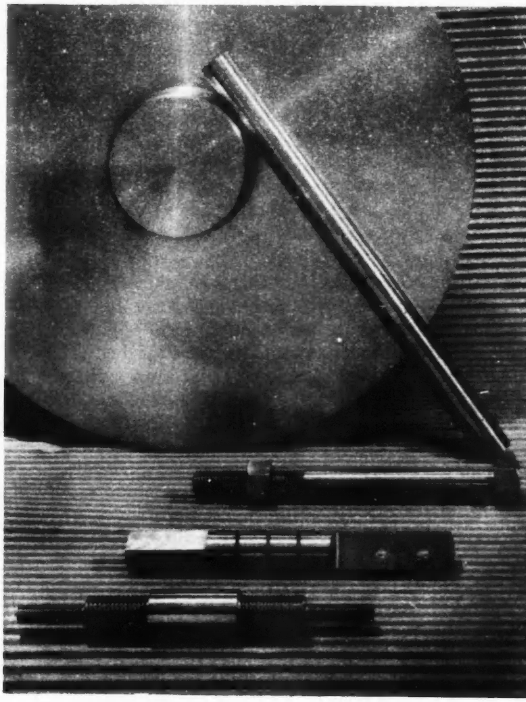

FIG. 5. Machined products made from titanium.

higher strength but lower elongation, that is, it can be deformed to only a small extent before fracture; in other words, it is brittle.

Fortunately, there are many metals which can be alloyed with titanium to increase hardness and tensile strength without causing appreciable embrittlement and loss in ductility. The most effective alloying elements at present known are iron, manganese, chromium and aluminium. Ductile alloys are already available with tensile strengths of as high as 70 tons per square inch, which is exceeded only by the strongest alloy steels. Moreover, the density of titanium, 4·5 gm./c.c., is little more than half that of steel, so that for the same weight, titanium alloys are considerably stronger. They have, in fact, a better combination of high strength and low weight than any other available material, and this superiority is maintained at all temperatures up to 500° C. It is by virtue of this fact, in conjunction with resistance to corrosion, that titanium will find most of its applications. Above 500° C, the strength of titanium and its alloys falls off rapidly, and they are not, in general, suitable for prolonged use at such temperatures.

The potential uses of titanium cannot be discussed without reference to the cost of production. The present price of simple wrought forms is as high as £5 per lb., but even at this price the use of titanium is well justified in aircraft and aircraft-engine components, and to a limited extent in the chemical industry. Perhaps the most important present application is for the compressor blades of aircraft

gas turbines where strength to weight ratio at moderately elevated temperatures is of great importance. Other possible uses which lead to weight-saving in aircraft include shrouding for engine nacelles, hydraulic and pneumatic tubing, landing gear parts, bulkheads, firewalls, etc. The suggestion has frequently been made that titanium will be necessary for the skin of aircraft flying at supersonic speeds, which may be heated aerodynamically to temperatures above that at which aluminium softens. A recent American estimate has suggested that at present prices the annual consumption of titanium in that country will soon reach about 10,000 tons.

If the price were reduced to £2 per lb., the same estimate puts demand at some 20,000 tons per year. But a really large increase in output will probably come only when the price is brought down to about £1 per lb., for then titanium could replace stainless steel throughout both military and civil aircraft, and would also be widely used in automobile, railway and shipbuilding engineering and for chemical and surgical equipment. Total American production might, in fact, approach something like 100,000 tons per year.

These considerations emphasise the importance of reducing the cost of titanium production, and it is interesting to speculate on ways in which this may be done in the next few years. The present difficulties of making sponge and converting it to ingots and wrought end products may be summarised as:

(*a*) expensive raw materials,
(*b*) small batch production with high operating and investment cost,
(*c*) difficulty of maintaining uniform quality,
(*d*) inability to reclaim inferior and scrap material.

It has already been stated that very great reductions in cost appear unlikely to result from developments of the Kroll process. However, it may well prove possible conveniently to reduce titanium tetrachloride by agents other than magnesium, and to modify the process so that the titanium produced could be more readily separated from the by-products, perhaps by a continuous process. One attractive method which has been suggested is to feed the reaction product continuously into an arc furnace where volatilisation of by-products and melting of the titanium would be effected simultaneously. The problem of recovering titanium scrap is already receiving much attention, and it is expected that this will be solved in a comparatively short time.

An electrolytic process for the production of titanium would offer great attractions, and indeed it is frequently reported that such processes have been discovered. The evidence for production of metal from an aqueous solution even in the laboratory is not convincing, and the prospect of producing large slabs of metal seems remote. Reports of processes based on fused salts also appear, but so far all such processes have been successful only for metals which can be withdrawn in the molten condition or which float on the electrolytic bath, e.g. aluminium, sodium and calcium. It is difficult to see how any such process can be devised for a metal melting at over 1700° C.

Perhaps the ideal process would be one in which the oxide was reduced with carbon in a form of blast furnace, or in which titanium tetrachloride was reduced with hydrogen. Both these reactions are believed to be thermodynamically possible if a sufficiently high temperature is reached, and perhaps some day it will be possible to build a suitable plant and risk this expensive experiment. The field is at present wide open for such technological endeavours, and he would be a rash man indeed who said that titanium would not some day appear in our homes as a metal in common use.

PROGRESS OF SCIENCE—*continued from page 107*

his lecture was appropriately entitled "A Century of Photography". The last hundred years cover nearly the whole of the history of photography. As a widely practised art photography dates from 1839, when Louis Daguerre and Fox Talbot brought out their processes, known respectively as Daguerreotype and Calotype. The first recorded photograph was actually taken some years earlier—in 1826, to be exact, when Niepce produced a photograph upon a polished pewter plate coated with a special kind of bitumen which is rendered insoluble by prolonged exposure to light. Mr. Wratten's lecture has now been published in the R.S.A. journal of March 6.

Readers will be interested in two books written by G. A. Jones, a frequent contributor to DISCOVERY, which have just been published. The first of these is a semi-technical book with the title *Modern Applied Photography* (Temple Press, 9*s.* 6*d.*), which provides a useful introduction to this subject. It discusses such topics as the uses of infrared and ultra-violet photography, radiography, photography in nuclear research, and the recording and analysis of motion by various photographic techniques. Another chapter of the book which will interest scientific people is concerned with the micro-filming of documents, which is likely to become increasingly important in the future for it can solve the problem of compressing the ever-increasing volume of scientific literature into a reasonable space. The scientific library of the future may well contain nothing but micro-film copies of books and periodicals, though this is not likely to happen for a long time. But the method could be exploited more than it is at present by the scientific world, which finds such difficulty in maintaining reasonably comprehensive collections of books and journals in face of the increasing output of printed scientific documents.

The second book by G. A. Jones is *High Speed Photography* (Chapman & Hall, 42*s.*). This monograph in its 311 pages gives careful and detailed descriptions of the techniques that have been found useful in practice, and there is an excellent and up-to-date bibliography. It comes as something of a surprise to learn from this work that hardly any fundamentally new methods have been devised since Egerton introduced the gas-discharge lamp in 1930 to give the succession of very brief flashes required. Since that year many refinements have been added to existing techniques, but few revolutionary methods have been invented.

THE COELACANTH FISHES

ERROL WHITE
D.Sc., F.G.S.

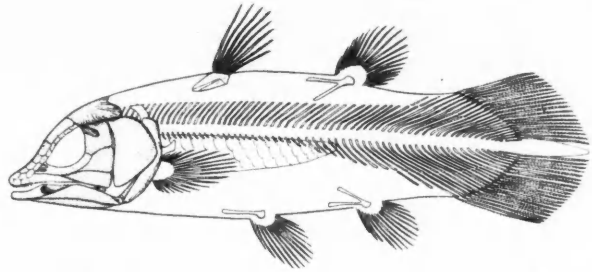

FIG. 1. The last known fossil coelacanth, *Macropoma lewesiensis*, from the Chalk of south-east England. In this restored figure the scales have been omitted to show the bony air-sac lying under the backbone. (*After Smith Woodward; courtesy, Palaeontographical Society, London.*)

Now that most of the excitement over the discovery of a second specimen of a living coelacanth fish has died down for the time being and Professor J. L. B. Smith's preliminary account of the creature has been published in *Nature*, Jan. 17, pp. 99–101, we may make an assessment of its importance.

The landing of the first coelacanth late in 1938, it will be recalled, created one of the biggest sensations for many years among zoologists, and rightly so, for it showed the continued existence of an archaic type of animal, that scientists thought had disappeared some seventy million years ago, at the end of the age of the great reptiles: the dinosaurs, the marine ichthyosaurs and plesiosaurs and the flying pterodactyls. So far as we then knew the last coelacanths swam in the shallow seas which at that remote period covered what is now the south of England, when the white chalk, the characteristic feature of the cliffs of our south-east coastline, was being formed as ooze on the sea-floor.

The impact of this discovery on the mind of the general public was extraordinary: for fishes do not often make news items in daily papers, and probably it can be justifiably claimed that no fish was ever considered more newsworthy.

The circumstances of the discovery of the second coelacanth just before last Christmas were equally dramatic, but in a different way and one more likely to appeal to popular imagination—it will be remembered how Professor Smith, who had for fourteen years sought for it up and down the coast of East Africa, flew some 2000 miles to the remote Comoro Islands in a successful attempt to beat the weather and the forces of decomposition. His haste to reach the second coelacanth was dictated by the need to ensure that this specimen should not suffer the fate of the first—that specimen was little more than a stuffed skin by the time it came into his hands—for he wanted to be able to preserve the whole fish so that its internal organs should be available for scientific investigation.

If anything, this event aroused even more interest than the first, although the experts had been waiting for it to happen, for it was considered most unlikely that the first specimen (which Professor Smith called *Latimeria chalumnae*) was the very last of its kind. Sooner or later another specimen of *Latimeria* seemed certain to be caught as a result of the intensive search that its appearance had provoked. But what we had not expected was that the next specimen should belong to an altogether different kind, now named *Malania anjouanae*. The coelacanth story has now reached the stage when the existence of a third and smaller species is hinted at. For a single isolated animal to have been overlooked is understandable enough, but when it comes to two or three, constituting a small fauna, it is quite another matter and suggests further inquiry into the reasons for their separation.

The name *Coelacanthus* was first given by the great Swiss naturalist, Louis Agassiz, in 1839, to a fossil found during work on one of the early railway cuttings at Ferryhill, about seven miles south of Durham. It came from the Marl Slate, which is of Permian age and therefore about 200 million years old, and the name is derived from the Greek, κοῖλος hollow, and ἄκανθα a spine, because the fin-rays (i.e. the slender bones supporting the fins) were ossified only superficially, leaving large internal cavities in the fossils. Since the time of Agassiz many different genera of coelacanths have been described from various formations and areas, starting from the Upper Devonian and ending, as we once thought, in the Upper Cretaceous, a span of some 230 million years.

During this vast period of time the coelacanths changed very little in general appearance (Figs. 1 and 2). Many of the fossil forms were quite small fishes, some only a few inches in length like the Carboniferous *Rhabdoderma* and the Triassic *Whiteia*, but one, *Mawsonia* from the Cretaceous rocks of Brazil, probably exceeded in size the living specimens, the larger of which was five feet long.

Their most striking feature is provided by the paired fins (the first two lower fins seen in Figs. 1–3) which correspond to our arms and legs and which are borne on muscular scaly lobes instead of being fanlike and coming straight from the body, as in more familiar fishes. A similar single fin is to be seen just behind the vent about midway between the hinder pair and the tail, and another lies opposite it on the back. This last fin is the posterior dorsal fin; there is another one in front of it and placed half-way towards the back of the head, called the anterior dorsal fin, but this always lacks the scaly lobe.

The form of the tail is also peculiar. There is no marked constriction in front of the fin: the scaly body just narrows

rapidly and evenly, and then continues backwards as a narrow strip dividing the fin-rays into two equal parts above and below it, and in many coelacanths it continues beyond them to form a small supplementary tail (Fig. 2). There was one other extraordinary feature. In fossil fishes as a rule little or nothing is found of their 'insides' since the contents of the body-cavity—heart, liver, intestines and so on—were soft and decayed rapidly, but in the coelacanths the air-sac was sheathed in bony scales and therefore largely rigid. In all probability this organ was a functional lung in the ancestors of the coelacanths, and is so in their living nearest relations, the lung-fishes (Dipnoi). In most modern fishes it persists as a long membranous bag which acts as a hydrostatic organ, the gaseous content being adjusted to keep the fish buoyant at any particular depth. Its remains are sometimes seen as a silver streak in the breakfast herring.

Latimeria, the specimen caught in 1938, shows all the external features characteristic of the coelacanth group, some in an exaggerated form. The small supplementary tail is well developed, and the lobes of the scaly-based fins are much lengthened, in fact considerably more so than in the fossils, so that they stand well away from the body looking very much as if they really were on the way to becoming walking limbs. This fish was five feet long, weighed 127 lb. and was steel-blue in colour.

The new fish, which is a male, is some six inches shorter. It looks similar except that it lacks the supplementary tail-fin and the anterior fan-like fin on the back (Figs. 3 and 4). It was the absence of these two typical coelacanth features that was apparently the chief reason why Professor Smith referred it to a different genus, *Malania*; but if one looks carefully at the published photograph of it (Fig. 3) one sees an unnatural-looking dip in the back where the front fin should have been, and as Professor Smith says, the scales there are irregularly arranged so that the absence of the fin may be due to an injury when young. Moreover, the tail is very blunt, and not only is there no supplementary fin projecting beyond it (cf. Fig. 2) but the fish lacks that scaly extension of the body, which in all other coelacanths separated the upper and lower halves of the tail-fin. Instead there appears to be an obvious irregularity in the tail where this extension could have been (Fig. 4). This suggests that the absence of the extension is due to damage. It is true that other differences between the two fishes are said to exist. For instance, the scales are described as being smaller in *Malania*, and Professor Smith states that the suspension of the lower jaws is different, but the first point is not clear in the photograph and the second seems rather unlikely: the head has evidently been badly knocked about, and the lower jaws seem to be thrust forward unnaturally. Anyway, until full details are forthcoming, we must reserve judgment as to whether the two fishes really are so different or whether *Malania* is not just an unfortunately mutilated edition of *Latimeria*.

There is one special character of these two fishes that has attracted much attention, and that is their extreme oiliness, which has been linked by some scientific people with the theory that the mineral oils, such as petroleum, were derived from the decay of vast numbers of fishes and other creatures that have lived and died throughout the ages. Although this explanation of petroleum formation is favoured by many geologists, it must be emphasised that the composition and qualities of animal oils and mineral oils are very different and, so far as I know, there is as yet no process known by which the one can be converted into the other.

The two most popular ideas about the coelacanths are that they are either 'living fossils' millions of years old, or else 'missing links' that will somehow throw light on Man's remote ancestry.

THE DATE OF THE FIRST COELACANTHS

First of all let us get it quite clear that the individual fishes are not abnormally old, probably no older than any other fishes of similar size, and are five, ten or perhaps twenty years at the most. Nevertheless the term 'living fossil' does serve one useful purpose, as it emphasises the fact that these coelacanth specimens belong to a type of animal that has survived long beyond its appropriate era. According to our ideas they ought to be extinct but are not. Perhaps a few remarks about geological time and evolution will make this point clearer.

Life as we know it on this planet is at least 600 million years old. It started first with the smallest and simplest types, and as the eras passed, higher and more complex animals and plants developed in a more or less orderly sequence. The coelacanths are first found near the middle of the sequence, some 300 million years ago, and it may help us to appreciate the vastness of this ancestral record when we recall that Man did not appear for another 299 million years, for the earliest known remains accredited to the genus *Homo* are rather less than one million years old.

From the discovery of their fossil remains we know approximately when each type appeared and how long it persisted. The fossils do not give us the time in years; that is done by physical methods, such as the lead ratio in radioactive minerals whose rate of disintegration is known; but once that has been fixed for a particular series of rock, then the fossils allow us to correlate it with other series with similar faunas or floras elsewhere. Thus fossils do allow us to identify and date the rocks in which they are found.

But our knowledge of the succession of life as applied to each individual type of animal or plant is empirical, the result of experience and something that cannot be calculated. We cannot foretell, for instance, how long any newly discovered form will continue, and we do not know why some creatures have persisted through countless ages, sometimes with little change, while others have made a brief and widespread appearance in the geological record, only to disappear as suddenly as they came. It is this last type that is most useful to the geologist, for they can be used to identify a particular stratum and so enable him to make precise correlations of strata over large areas.

The causes of extinction in nature are not well understood. Many animals and plants, of course, did not actually die out, but instead changed into more advanced forms by the process of evolution. Others undoubtedly did become extinct, and sometimes whole groups like the great reptiles, the dinosaurs, faded out.

A common explanation of extinction in animals is that

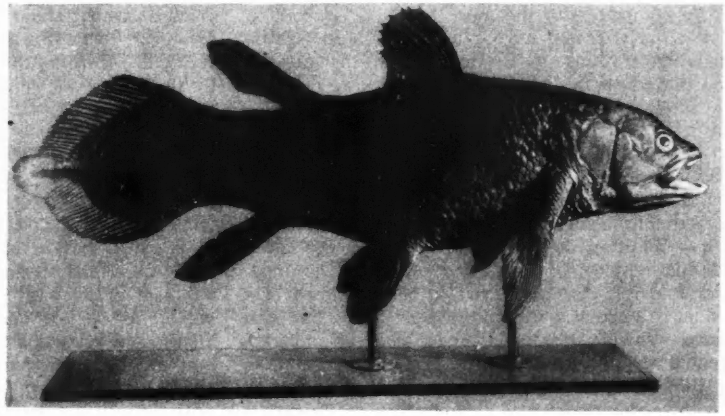

FIG. 2. Restored model of *Latimeria chalumnae*, the first living coelacanth found. About 5 ft. long. The membrane behind the first dorsal fin is fictitious.

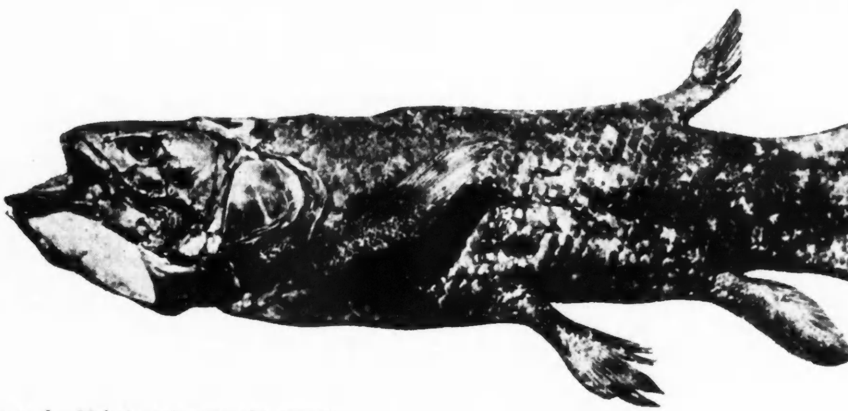

FIG. 3. *Malania anjouanae*, the second specimen of a living coelacanth, caught last December. About 4½ ft. long. (*Courtesy, "Nature" and Prof. L. J. B. Smith.*)

FIG. 4. The tail and hinder fins of *Malania* in greater detail. (*Courtesy, "Nature" and Prof. L. J. B. Smith.*)

with limited food supplies the more primitive types were unable to compete with the more highly developed; in some cases the latter may have actually preyed upon them, especially their young, as the early mammals are said to have preyed on the untended eggs of the great herbivorous dinosaurs—and of course when they became extinct, then their flesh-eating relatives that fed on them had to disappear also. But earth movements, resulting in the gradual rising or sinking of the land, must have been a prime factor; for the changes in the level of the land surface may well have affected the climate adversely, and that in turn would affect the animals (especially cold-blooded animals like reptiles) or their food supplies. The possibility of epidemic diseases must also be considered. On more than one occasion the big game of Africa has been decimated over wide areas by rinderpest, and such an occurrence could well put 'paid' to a weakling species. Anyway, it was thought until 1938 that this group of fishes had gone with the dinosaurs and their sudden reappearance after an interval of 70 million years gave the scientific world—and other people too—something to talk about.

It is this long absence from the geological record that makes the reappearance of the coelacanths so interesting, for in the animal kingdom as a whole so-called 'living fossils' are not uncommon. Indeed the coelacanth's own, if distant and rather degenerate, cousins—the lung-fishes—still exist on three continents. The whole native fauna of Australia is an archaic survival that has been saved from extinction by that continent's isolation. We also have the text-book case of the Tuatara, the sole survivor of a group of lizard-like reptiles, the Rhynchocephalia, that flourished in Triassic times, more than 150 million years ago.

However, not all living fossils are by any means the struggling survivors of once important groups—the all too successful cockroaches represent a type of insect that goes back to the time of the great coal-forests, while some of the living sharks and skates have a respectable ancestry of more than 100 million years.

There is, however, one important difference between the history of most of the animals that have been mentioned and that of the coelacanths. Whereas most of the former became adapted to a certain type of environment and stuck to it, the coelacanths have continually changed their habitat. The first primitive types of the Devonian rocks (the Diplocercids) were marine, but the succeeding forms of the Carboniferous period were mostly inhabitants of the fresh waters. Later, in Triassic times, they went into the shallow seas, venturing into rather deeper waters as time went on. So one of their claims to zoological fame is *adaptability without obvious structural change*.

FIG. 5. Diagram showing the relative numbers of species of coelacanths recorded from the different periods in the geological succession. (*After Prof. F. E. Zeuner.*)

How common coelacanths were in the past it is not easy to say, for fossil numbers do not always by any means reflect the rarity or otherwise of the living animal owing to the varying chances of preservation and discovery.

On the whole coelacanths are rather rare as fossils, although occasionally in a particular locality they have proved to be not uncommon; in one instance, many hundreds of fossil coelacanths were found in Triassic rock that was being excavated for the foundations of a new building at Princeton University.

The accompanying diagram, which also gives a useful time-scale, shows the relative numbers of known different kinds at various periods, and the rise and decline in actual numbers of individuals probably follows the same pattern. The absence of the coelacanths from the geological record for the last 70 million years is most intriguing, and suggests that during this time they lived in the somewhat deeper parts of the seas, to which they had retreated in the face of competition, and where sedimentation would have been slight and the chances of their remains being preserved would therefore have been slim. A similar suggestion was made regarding the living forms when the *Latimeria* specimen was caught fourteen years ago, for it is clear that they inhabit regions not commonly fished. However, this suggestion has been questioned since we now have reason to believe that a few are caught every year in the shallow, rocky waters around the Comoro Islands. Yet the landing of two or three specimens a year in a particular area which is regularly fished does not necessarily mean that the focal point is in that area. Fish do wander, and they also make seasonal migrations—both specimens, we may note, were caught in December.

It is difficult to understand how any creatures so unchanging as the coelacanths could be considered as 'missing links', since it is the essence of a biological link that it should connect two different types, and that is just what coelacanths did not do. But they do belong to a curious archaic type of fish—the Fringe-finned fishes (Crossopterygii)—that differ in many ways from those with which most people are familiar.

The average person knows perhaps a score or two of fishes, and these are all very uniform in structure, in spite of great variation in shape and colour: they are nearly all of the type known as 'teleosts'. More interesting to the scientist are the lung-fishes, bow-fins and gar-pikes, but these are rarely kept except in the larger aquaria in zoos.

Not all fishlike creatures are really fishes. Apart from the whales, dolphins and porpoises, which are mammals, and the extinct ichthyosaurs, which were reptiles, there are the eel-like lampreys and their kin, which belong to a much more primitive group.

True fishes belong to *three* very distinct types whose common ancestors have never been found. One type—

the *Elasmobranchs*—is represented by the sharks and skates, with their skeleton of gristle instead of bone, five or more open gill-slits and skin of shagreen. The second type—the *Actinopterygii*—includes the Teleosts which form the great majority of living fishes, with a bony skeleton, the fanlike fins, gill-slits hidden by the large gill-cover or operculum and the body covered with usually small thin scales. The third type (the *Crossopterygii*) comprises the coelacanths and their relatives; these are thick-scaled and lobe-finned, with the skeleton part gristle, part bone.

When we find the first traces of the Crossopterygii, some 300 million years ago in Devonian strata, they were already divided into three different groups. It is the very different subsequent fate of each of those three groups that is the crux of the coelacanth story. They all had rather long heavy bodies with thick, bony scales and lobed fins common to their kind, and to that extent were somewhat alike. However, two of these groups had other very important characters: in addition to gills, which all fishes possess, they had lungs by which they could breathe air directly, and internal openings to their nostrils so that they could breathe air regularly while keeping their mouths shut and exposing no more than the tip of their snouts above water.

The first of the two lung-breathing groups was the Rhipidistia, for which there is no popular name as all of its representatives become extinct long ago. Among the Rhipidistia was a small progressive element which used their limb-like fins and their ability to breathe air to scramble ashore when the pools in which they lived started to dry up in the hot seasons and to move overland to fresh waters. In the course of time they became more and more adapted to spending part of their life on land, their paired fins actually developing into true legs. When this stage was reached they were no longer fish, but primitive amphibia. From some of these early amphibia evolved the scaly reptiles, which are entirely independent of water except for drinking, although some, like the crocodiles and the turtles, have returned to an aquatic mode of life. Still later a branch of the reptiles gave rise to the mammals. Thus it will be realised that it was the Rhipidistia which were *our* remote ancestors (Fig. 6).

The second air-breathing group of fish apparently lacked the ability to evolve further and became somewhat degenerate. They stayed in their drying-up pools and just used their lungs to tide themselves over until the next wet season. Nevertheless, by their ability to endure unpleasant conditions they have so far avoided extinction. Lung-fishes (Dipnoi) are still to be found in pools, swamps and intermittent rivers in parts of Australia, Africa and South America.

The third group of Fringe-finned fishes were the coelacanths, and their story is the least eventful of them all: it shows remarkably little in the way of evolutionary change. The coelacanths had two great disadvantages compared with their relations. They had no through passage from their nostrils into their mouths—whether they once had one but lost it early, or whether they never had such a passage the records do not show—and, as we have already noted, their lung or air-sac was sheathed in bony scales. What purpose this served, scientists would like to know. It must have had a function of some importance, for it was a conspicuous feature in the fossils

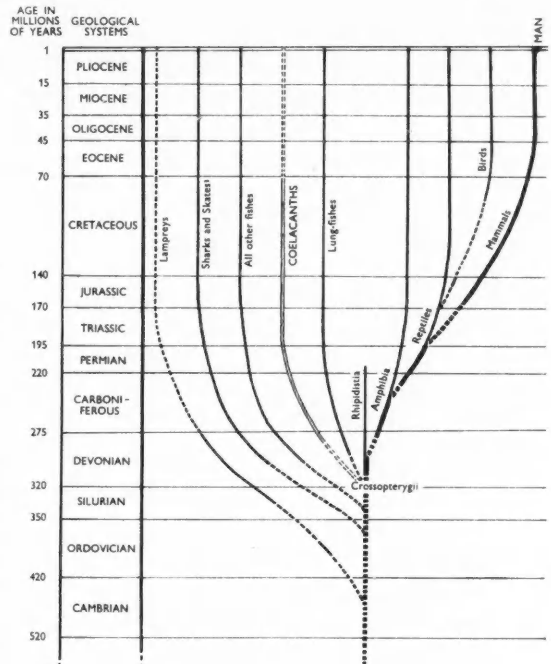

FIG. 6. Diagram showing the relationships of the coelacanths to other backboned animals and their distribution in the geological succession. Time in millions of years.

for about 200 million years: it may have acted as a resonator, increasing their perception of sound-waves, as the air-sac does in some modern fishes. We do know, however, that the coelacanths neither went up the scale of life nor down—they just remained coelacanths. They were related to our far-off ancestors, the Rhipidistia, but they were never in the direct line of evolution and represent a sort of biological backwater.

As to the claim that they may throw light on our remote ancestry this can be said: since the first coelacanths were related to the ancestral line, and since they have changed so little in outward form, they may have preserved some of the primitive features common to them both. But whether they will in fact tell us so very much more than we have already learnt from the other surviving group of Fringe-finned fishes, the lung-fishes, remains to be seen. In any case, whether it proves to be primitive or otherwise the internal anatomy of these curious fishes is certain to be of great interest to the specialist. The matter of the ossified air-sac has been already noted, although disappointingly there is no mention of such an organ in the preliminary accounts, which lay emphasis on the possession of a spiral valve in the intestine. The latter character is less remarkable than the absence of the spiral valve would have been, as it commonly occurs in the more primitive living fishes. But there are plenty of other details we should like to know about them and Professor Smith's detailed report will be awaited with the keenest interest by zoologists throughout the world.

FIG. 1. The word 'tilth' originally meant the act of tillage, but it has come to mean the physical condition of a soil. These two photos show difference in tilth between two soils. In both cases the land was photographed immediately after ploughing. (*Left*) This loam has a good tilth, and is suitable for sowing seed. (*Right*) This clay will need a good deal of weathering before it has the tilth required for a seedbed.

SOIL TILTH: ITS SCIENTIFIC ASPECTS

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It is now widely appreciated that food has always been a scarce commodity in many parts of the world, and recently it has become scarce in this country, because we can no longer import the immense quantities of food from overseas that we could do before the war. This has presented a challenge to British farmers and they have responded by increasing food production from our land very considerably. But undoubtedly the amount of food produced in Britain could be increased much further if full use was made of all our present scientific knowledge. One important aspect of the present limited utilisation of existing knowledge is the inadequate use that is made of fertilisers on much of our land. This is partly due to the fear that fertilisers will harm the soil, probably by causing it to lose its tilth, and so making it less suitable for crop production.

Tilth is an extremely important practical concept, but it has given the research workers great difficulties in the past, firstly because several quite different soil properties contribute to it, and secondly because all operations on the farm which affect the tilth such as different methods of cultivation, applying farmyard manure or using grass leys, do many other things besides affecting the tilth. Now farmers are not research scientists, and as long as a practice works they do not have to concern themselves with *why* it works, although this does not prevent them from having their own opinions on this question. But this approach has greatly delayed appreciation of the relative importance of the various factors that go to make up this illusive property of tilth (Fig. 1).

As so often happens in research, our understanding of the factors that go to make tilth has come from fundamental scientific work not concerned with tilth at all. We now know at least some of the important conditions that must be fulfilled before plants can grow really satisfactorily. They fall into three groups: the soil must form a suitable home for plant roots to live and grow in; it must contain enough plant foods in a suitable form for the plants to use and in the right proportions; and there must be an adequate supply of water close to the roots.

Now the soil can only be a good home for plant roots if it contains channels or pores large enough for fine roots to enter, if there is an adequate supply of air around the roots and if there are no root poisons in the soil. All these conditions are increasingly coming under the control of the farmer, although they are easier to obtain in some soils than in others.

OXYGEN AND THE LIVING SOIL

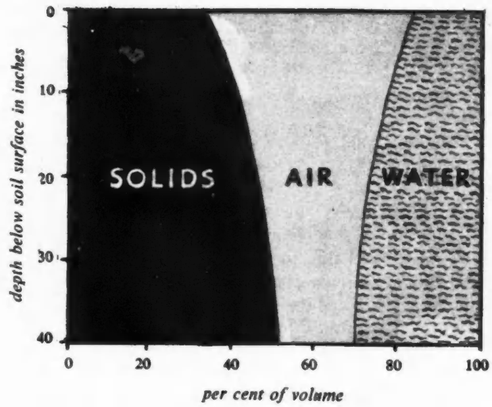
There are only two groups of root poisons of any general importance—those that accumulate in acid soils, and those present in badly aerated soils. Acid soils commonly contain too high a concentration of aluminium and divalent manganese ions; sometimes there is also a too low concentration of calcium ions as well. All these conditions are rectified by raising the soil's pH by adding lime—either

calcium oxide, calcium hydroxide or finely ground calcium carbonate. As the pH rises the aluminium ions are precipitated as insoluble aluminium hydroxide, the divalent manganese is oxidised to insoluble manganese dioxide (probably by the action of micro-organisms), and the liming material adds calcium ions. Poor aeration allows carbon dioxide to accumulate in the soil and also results in the microbiological reduction of the sulphates that are always present in soils into hydrogen sulphide, which is very toxic to plant roots. The same condition makes for microbiological reduction of ferric to ferrous iron, which can be present in much higher ionic concentrations than ferric, and so also becomes toxic; and it may also lead to the production of some reduced organic compounds that have not been isolated. Getting an adequate oxygen supply to the roots cures all these troubles, which never arise if an oxygen supply to the roots is assured. Thus the two conditions for good root growth that need further consideration are (*a*) space for the roots to grow into and (*b*) a good oxygen supply; it will be shown later that if adequate oxygen supply is assured, there will also be sufficient space for the roots to grow into.

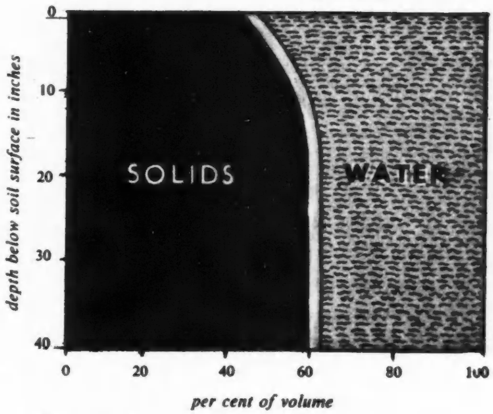
This problem of assuring an adequate oxygen supply to the roots is of great importance in all soils, and it can be extremely difficult to solve in some. The primary reason for this is because the soil is full of living organisms, which are continually removing oxygen from the soil air and replacing it with carbon dioxide, as do the plant roots; so the problem of soil aeration is to ensure a sufficiently rapid replacement of the carbon dioxide produced in the soil by oxygen from the atmosphere—the only source of oxygen for most soils. Many mechanisms for carrying out this transfer have been suggested, and the current theory is that the most important mechanism is that of simple diffusion. The carbon dioxide concentration in the soil air around the plant roots is higher than in the atmosphere, so it tends to diffuse along any available air channels into the atmosphere; correspondingly the oxygen content of the soil air is lower than in the atmosphere, so oxygen diffuses down these same channels. This is held to be the only mechanism that is anywhere near adequate to account for the observed rates of transfer of oxygen and carbon dioxide. The most important factor controlling the rate of diffusion is the volume of the air channels that connect the soil zone which one is considering with the atmosphere, and this volume must be considered separately in each layer of soil above the chosen zone. Hence, provided that there are enough channels containing air to connect the roots with the atmosphere and that there is no soil layer where this volume becomes too small, the roots will get all the air they need, and the carbon dioxide they produce will diffuse away without harming them.

The problem of soil aeration is thus the problem of the maintenance in the soil of an adequate volume of channels connected to the atmosphere and containing air. Why is this difficult? The principal reason can be appreciated immediately it is realised that the spaces in the soil that do not contain air must contain water. Hence the drier the soil, the greater the volume of air—and hence of air channels—in the soil, and the better will be the aeration around the plant roots. On the other hand, the wetter the

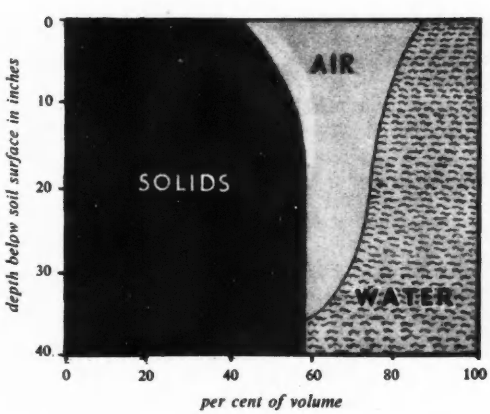
FIG. 2. The difference between air contents of a wet, well-drained clay and a sand.



(*a*) Wet, well-drained sand; note high proportion of air.



(*b*) Wet, well-drained clay pasture; low air content.



(*c*) Same clay pasture, after dry summer. Air content has risen, water content having been reduced by the crop.

soil, the smaller the volume of channels containing air, and the worse the aeration around the roots. Problems of soil aeration are therefore almost entirely restricted to wet soils —all soils that are dry from the surface downwards are well aerated (Fig. 2).

How can one ensure that there shall be an adequate volume of air channels in wet soil? Only drained soils can contain air in wet weather, for the rain that falls on the soil surface will fill all the air channels unless there is somewhere for it to drain to. But drainage by itself does not necessarily guarantee there will be any air channels, for this depends on the size of the pores. If a soil is well drained and there is no water table in the soil (i.e. if no water could be got from a well dug in that soil) then the factor that controls the size of the channels out of which water will drain is the *viscosity* of the water. This point needs expansion. Water flows much more easily through a wide pipe than a narrow one, because when water flows through a pipe, the layer of water nearest the wall is stationary, and the velocity of flow of each layer increases from the wall to the centre. If the pipe has only a very small diameter, it is extremely difficult to get an appreciable velocity of flow in the centre of the pipe, hence to get any appreciable volume of water flowing through it. Applying this to soils, fine pores offer so much resistance to liquid flow that, in such a constantly changing environment as the soil, they have not time to get emptied by drainage. It appears in fact that water can only drain with reasonable speed out of channels larger than about 0·05 mm. (1/500 in.). The problem of aeration is thus to ensure first of all that the soil is drained, and then that there is an adequate system of pores at least 0·05 mm. in size beginning in the soil surface and extending down to below the root range of the plant. Plant roots can enter pores of this size quite easily, so that if the soil is well

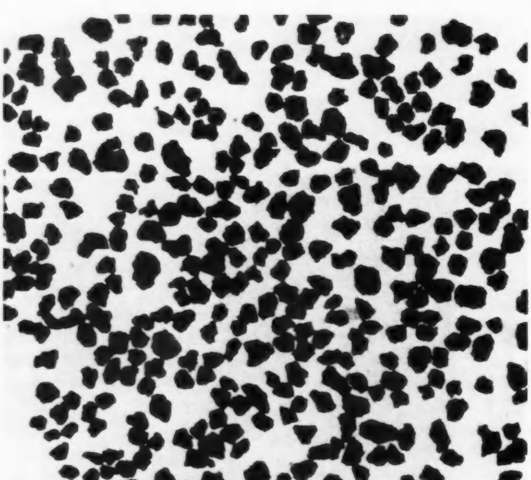


FIG. 3. A soil composed of crumbs of this size would have an ideal structure.

aerated when moist, there is adequate room for roots to grow in.

CRUMB SIZE: A CRITICAL FACTOR

What does such a soil look like? It is found in practice that the ideal conditions for plant growth are provided by a soil having no crumbs larger than 5 mm. (1/5 in.) or smaller that 0·5 mm. (1/50 in.). Crumbs smaller than 0·5 mm. will usually have pores between them that are smaller than 0·05 mm. and so these will not be emptied of water by drainage; such crumbs will also tend to fall into the air pores, reducing their size to below this critical value. A soil in which most of the crumbs are larger than 5 mm. may have too large a proportion of its volume inaccessible to plant roots, and the pores between the crumbs are likely to be so large that a root growing into them may have difficulty in getting enough water (Fig. 3).

Clay soils form an example of soils which tend to have clods that are much larger than this optimum size of 5 mm., and the problem of managing such soils is obviously to adopt measures that will encourage the maximum number of small crumbs to be formed. It is theoretically not strictly necessary to get all the clods down to this size if instead they can be converted into sponges, full of channels that are larger than 0·05 mm. and so capable of being emptied of water by drainage. But this desirable alternative seems rarely to happen in this country, for such spongy clods tend under our moist climatic conditions to fall down into much smaller crumbs; though they seem to be more stable, and occur fairly commonly, on certain types of well-drained red soils in the tropics and sub-tropics.

RAIN DAMAGE TO SANDY SOILS

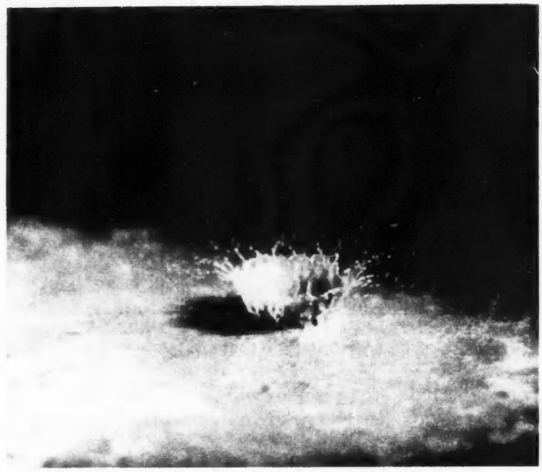
Sandy soils often possess this optimum structure when well managed. If one digs up a plant from such a soil, one finds it has a very well-branched root system, capable of tapping a large volume of soil for water and nutrients. In the management of sandy soils the difficulty which is encountered is that of preventing individual sand grains falling off the very friable crumbs and blocking the air channels between them, so the pores become too fine to be emptied of water by drainage. Hence the art of managing sandy soils lies in maintaining the sand particles in spongy clods. The greatest danger to the surface tilth of sandy soils is, in fact, heavy rain. Large and therefore fast-falling raindrops have so much kinetic energy that they can easily break up the rather weak crumbs when they hit them (Fig. 4). Further, these drops splash when they hit the soil surface, from which the small droplets constituting the splash remove the finer sand grains. When the droplets return to earth, these fine sand grains proceed to block any coarse pores in the soil surface into which they fall. The surface pores thus get sealed, and the whole surface 'caps' or 'pans'; that is to say, a compact layer is formed at the soil surface in which all the pores are too fine to let water penetrate the layer from above; the water which does find its way into such fine pores cannot drain away. Even when the surface water resulting from a heavy rain shower has run off such soil, one is faced with the fact that no longer are there any air channels left to connect the air spaces in the subsoil with the atmosphere, and this can soon be disastrous for the

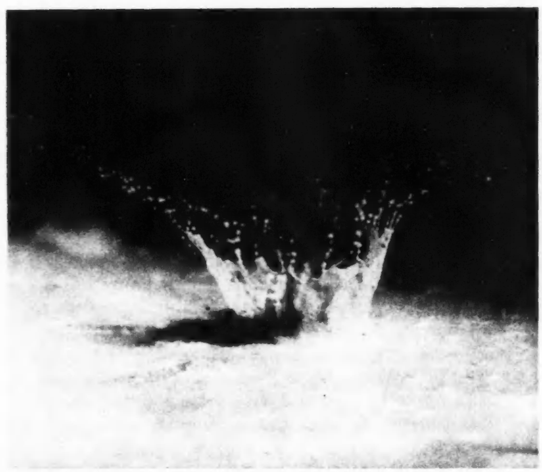
FIG. 4. The effect of a raindrop on loose, moist soil is vividly shown in this series of photographs taken by W. D. Ellison, the American expert on soil erosion.

(*b*) the raindrop has just hit the soil surface, and is being broken up into many small drops at the same time as it is loosening the soil particles.

(*c*) the energy of the raindrop has been dissipated partly into muddy droplets and partly by making a hole in the soil surface.

(*d*) the loosened wet soil around the crater is falling in around the sides.





crop in warm weather. For under these conditions the concentration of carbon dioxide in the soil air can rise tenfold in a day and the active roots will soon be harmed, particularly in summer time when this effect is most likely to occur, as they are more susceptible to damage by bad aeration in warm than in cool weather. It is under these conditions that hoeing the soil shortly after rain, whilst the surface is still moist, may be so strikingly beneficial to the crop, for hoeing allows the coarse pores in the subsoil to have access to the atmosphere once again.

The methods the farmer has at his disposal for creating more soil pores or soil crumbs of a desirable size are cultivation techniques, suitable crop rotations, the use of organic manures and mulches, and the encouragement of earthworms. Ploughing, cultivating and harrowing loosens the land, and increases the number of very wide pores, though the exact effect upon pore size depends on the crumbliness of the soil; digging does the same thing. With a structureless clay digging produces large solid lumps of clay with very wide spaces between them; on the other hand, digging a friable loam gives a far greater number of spaces (that are narrower than those in clay soil) because the lumps break up on being turned over. On the less friable soils the actual cultivation operations only have a minor direct effect: their importance is that they expose the soil to the weather.

Weather has a two-fold action on large clods. When a moist clod dries it shrinks, and when the dry clod is wetted it swells; since these shrinkings and swellings do not take place uniformily, and for other reasons also, the clod cracks and falls into smaller crumbs. Again, when a wet clod is frozen in winter, the water in the coarser pores freezes and the expanded volume of ice causes some shattering of the clod. Thus an important part of the art of cultivating such soils is to produce conditions allowing the

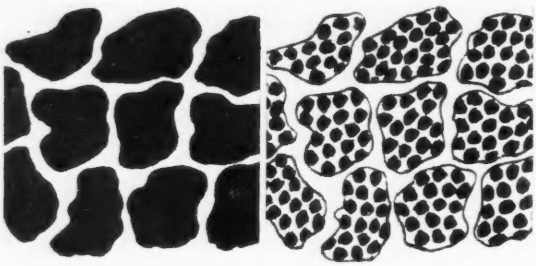


FIG. 5. How weathering can bring about the 'mellowing' of solid soil clods. (*Left*) The original clods, which are structureless masses with wide pores between. (*Right*) Each clod has weathered down to a mass of smaller crumbs; the general shape of the clod remains, but the clods are now almost sponge-like, and full of medium-sized pores.

maximum depth of weathered crumbs to be produced, and then to produce as deep a seedbed as possible from them (Fig. 5).

Crop rotations can also help to produce good tilths in difficult soils, for some crops (e.g. certain grasses) produce a very large number of strong-growing roots which in dry summers remove the moisture from the soil and proceed to ramify into every little crack that develops during this drying process. Many of these cracks will not seal up again fully next winter, because the dead roots hold them open, so that next summer the cracks open easier, providing channels whereby the roots can penetrate the soil quicker and more strongly. Hence after a few years in a suitable and well-managed grass, the soil will be found to be much more crumbly and friable when next the land is ploughed.

Earthworms can also increase the crumbliness of the soil, for they burrow through the soil, swallowing much of the soil they have to remove in the process; and when this soil is cast, it is in a crumbly and friable condition. But earthworms can only flourish and contribute appreciably to the soil tilth if firstly they are not too seriously disturbed, and ploughing appears to be a very serious disturbance; and secondly if they are given an abundant supply of food. Now lightly grazed pastures often fulfil both these conditions, and this is being made use of in present-day orchard management. Trees are often harmed if their shallow surface-feeding roots are cut by cultivations. The presence of too many weeds growing in the orchard will also reduce the crop of fruit. The trees suffer no such harm if the land is kept under grass, which is mown periodically.

Producing pores and crumbs of the right size is, however, only half the problem of good management, the other half is to try and maintain the good distribution throughout the growing season. As already mentioned, the soil surface is the most critical part of most soils—if the tilth is maintained there, it is very unlikely to be spoilt below—and the most difficult time to maintain the surface tilth is when the soil is bare. All methods of protecting the surface work on one of two principles: either they prevent the raindrops actually hitting the soil crumbs, or else they strengthen the soil crumbs (particularly when wet) so they offer much greater resistance to break-up.

The principal method of protecting the soil surface from raindrops is to cover it with a mulch of dead vegetation; a cover of living vegetation can be used to give the same protection if it does not interfere with the main crop. The impact of the raindrops it taken by the dead or living leaves or straw, and only slow-moving water touches the soil surface. The practical difficulties of applying these methods can be very considerable, as quite large weights of mulching material are needed per acre. The method is easiest to apply where the land never need be ploughed and where any cultivations necessary can be done in the soil under the mulch. These methods are becoming increasingly important for preventing soil erosion as well as the run-off of water from the soil in semi-arid climates.

Soil crumbs can normally only be strengthened against break-up by raindrops if cementing substances are added to the soil, and these must usually be organic. Clay is a good cement, and it is added at the rate of 100–200 tons per acre to some of the blowing sands in the east of the country, but this is economically possible only under certain restricted conditions. Humic materials are the normal cements which can be produced in the soil by adding plant remains to it. The phrase 'humic materials' has been purposely used rather than the simple word humus to indicate that the dark-coloured organic matter in the soil is not a simple substance having a definite composition, but a mixture of variable composition. Further, some of the components need have no definite molecular composition but resemble polymerised plastics such as Bakelite rather than definite chemical compounds like protein or even like a cellulose chain. These components are not all equally effective as binding agents, and in fact some may be looked upon more as compounds suppressing the strongly cementing effects of clay particles in clay soils; they weaken the cohesion between the soil particles in clay clods, making them less sticky when wet and more friable when moist.

There appears to be a third group of cementing materials in the soil, associated with the roots of some grasses and lucerne, for land that has been down to grass or lucerne for a number of years is found to have an excellent structure when it is ploughed out, whether the soil is a sand, a silt or a clay. The mechanism of this action is not known, but it seems to disappear as the dead roots decompose.

Synthetic organic compounds, that are polymerisation products like plastics, are also being introduced to take the place of natural organic cements, for very large dressings of materials like farmyard manure or compost are needed to add enough of the important cementing substances to give the really stable structure needed by market gardeners, glasshouse growers and so on. These substances, called 'soil conditioners' of which Krilium is the best known, have been so recently introduced that there is not yet enough field experience with them for their value to be assessed. But it appears they are more likely to be of value in stabilising a good soil structure once it has been obtained than in helping an unkind soil fall into a good structure initially.

A good soil tilth can be stabilised if one has available sufficient composts, or perhaps synthetic soil conditioners, but both these commodities are scarce and expensive. It is therefore important to make the very best use of limited amounts, and for many soils that could be done if the compost was kept on the soil surface as a mulch or worked

into the soil surface. Here, however, a fundamental difficulty arises because soils are normally ploughed at regular intervals, and this ploughing inverts the soil, burying the surface mulch or the stabilised surface tilth and bringing up new soil from the bottom of the furrow. Conservation of tilth with minimum organic matter may therefore mean abandoning the plough.

We are thus brought to the fundamental question in soil cultivation—what do we really need to do when we cultivate a soil? Obviously part of the answer is to undo the compacting effect of the various implements and tractors that have had to go over the land, and to neutralise the effect of rain in dispersing the surface crumbs which results in the clogging of all the coarser pores in the top layer of soil. Cultivators and subsoilers which loosen the whole soil without inverting the surface soil can, under conditions of suitable management, be adequate for this purpose. But the other part of the answer is to kill weeds. Now in cool, moist weather, such as we normally have in this country for many months a year, the only cultivation method of killing weeds is to bury them by ploughing them into the soil; and the deeper they are ploughed in, the more effectively are the weeds controlled. Until recently this was the only method of weed control we had in moist weather, short of pulling them out by hand. Recently, however, a minor revolution in methods of weed control has been brought about by the introduction of chemical sprays which will kill some plants but not others. Thus many weeds can now be killed in corn crops, peas and pastures without harm to the crop itself. If suitable sprays can be developed to control all the weeds on our farms, and suitable rotations devised, it may be economically possible to rely on sprays as the principal agent for weed killing. This would ease the problem of maintaining a good stable surface tilth at the cost of dispensing with the plough, which in the past has been the key and symbol of good farming.

HOW SALT WATER AFFECTS TILTH

The recent disastrous floods make it worth while to add a postscript about the effect of salt water on tilth. Soil tilth can break down on wetting for a reason entirely

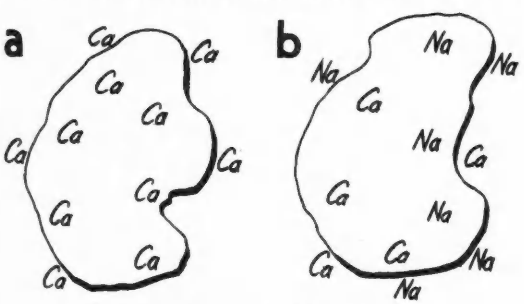


FIG. 6. Diagrammatic sketch of the difference between a clay before and after being flooded with sea water.
(*a*) the clay particle before flooding. Nearly all the cations around the particle are calcium; they hold the clay particles together as crumbs even when the soil is wet.
(*b*) after flooding with sea water. Many of the calcium ions have been replaced by sodium; these cannot hold the clay particles together if rainwater wets the soil.

different from mechanical shattering—the cements may lose their power to hold the crumbs together on wetting, with the result that the saturated crumbs break down to a mud, which forms large hard clods when it dries. The cause of this is that the wet clay and humic particles, instead of attracting each other and sticking together as they normally do, repel each other: they form what colloid chemists call a *deflocculated system*. Clay and humic particles carry a negative electric charge, and this is neutralised by cations, which are either adsorbed on the particle surface, or diffuse from the particles into the surrounding liquid. In a normal soil over 75% of these cations are calcium and under 10% are sodium and potassium. Now clay or humic particles can only deflocculate if the ions dissociate strongly from their surface; calcium ions do not have this ability though sodium ions do, but only if the concentration of salts in the solution surrounding the clay particles is low. A high salt concentration prevents the layer becoming sufficiently diffuse to allow the particles to deflocculate. Hence if a crumbly soil in which sodium ions form an appreciable proportion (e.g. over 15%) of the exchangeable ions is wetted in water, the soil will fall down to a mud; but if it is wetted with a sufficiently strong salt solution, the crumbs will keep their shape (Fig. 6).

Normally, a soil in the humid regions can only acquire such a high content of exchangeable sodium if it has been flooded with sea water. The principal salt in sea water is sodium chloride, and when salt water gets on to the land and drains through into the subsoil, the sodium ions replace some of the calcium ions held by the clay and humic particles, leaving a soil high in exchangeable sodium. As long as sea water bathes these soil crumbs, the particles will maintain their shape, for sea water is concentrated enough to keep the particles flocculated; but as soon as the rain has washed the sea water out from the soil, the particles will deflocculate and the soil will degenerate to a mud. The remedy for this condition is to replace the exchangeable sodium by calcium again whilst there is still enough salt left in the soil to keep it permeable. This is usually brought about by putting gypsum (calcium sulphate), which is the cheapest neutral calcium salt, on the land, and as this dissolves in the rain water it will give a solution of calcium sulphate which will keep the soil flocculated and also allow the sodium to exchange with the calcium, and the sodium sulphate that forms will be leached out by rain water percolating through the soil.

Let us now turn to farmers' experience of the problems of working land after it has been flooded with sea water. At first, after the land has ceased to be waterlogged, it works well and can be got into good tilth easily—there is still enough salt in the soil to keep it flocculated. The land in this condition can be expected to give good yields of salt-tolerant crops such as sugar beet, mangolds and barley. But as the salt leaches away, the soil proceeds to lose its tilth and may become so difficult to work that one cannot get a seedbed the following year. If this stage is reached, it is too late to undo easily the damage done by the sea water: the process of deterioration is practically irreversible, and it now becomes apparent that the farmer should have put the gypsum on the previous year, when the soil worked well and there seemed to be no troubles.

SLEEP AND OXYGEN SUPPLY

CHAPMAN PINCHER

The layman's chief criticism of scientists is that they busy themselves with abstruse matters like atomic bombs while ignoring 'simple' problems like the common cold. This criticism is often difficult to counter and it is particularly so in the case of sleep, a phenomenon which takes up a third of human life but has been little explored.

Few physiologists have devoted their efforts to studying the mechanism of sleep in spite of the fact that its abnormalities cause much misery. Almost the only persistent worker in this field has been the Chicago scientist, Professor Nathaniel Kleitman. Interest in Britain, however, has been recently rekindled by experiments carried out by Dr. John Lovett Doust and his colleagues at the Institute of Psychiatry in the Maudsley Hospital, London. It is the purpose of this article to describe these experiments.

Dr. Doust's researches arose out of the discovery that changes in the oxygen saturation of a person's blood can be accurately measured by means of an instrument without puncturing the skin or incommoding the subject in any way which might result in false readings. The instrument, called an oximeter, works on the principle that the property of haemoglobin for transmitting a beam of light varies according to the amount of oxygen it contains. One type of oximeter can be focused on the vessels in the semi-transparent skin at the base of the finger-nail. Another type measures the oxygen saturation in the arterial blood of the fine vessels of the ear-lobe.

Measurements on healthy people show that during the day when they are wide awake the oxygen level of their blood is usually between 92% and 98% of saturation—the figure for 100% saturation being determined for each individual person by making him inhale oxygen until a stable reading is obtained.

Dr. Doust made his first tests of the oxygen state of the blood during various conditions of 'unawareness' on colleagues indulging in armchair snoozes after a heavy midday meal. Fig. 1 shows what happened in the blood of a 35-year-old man. As he dozed off and lost full consciousness the oxygen level gradually fell, but when a colleague entered the room to discuss a case there was a rapid rise in oxygen strength and a corresponding increase in alertness.

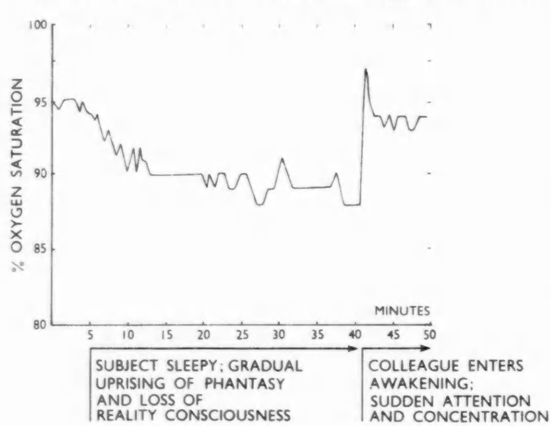


FIG. 1. Chart showing what happened to the blood-oxygen saturation of a healthy 35-year-old man as he dozed off in an armchair reverie and was suddenly awakened.

Doust then decided to study what happens to the oxygen strength of the blood during natural sleep at night and during the processes of dropping off and awakening. Six men and a woman, whose ages ranged between 22 and 36, volunteered to take part in the experiments.

To make the tests as natural as possible each volunteer changed into night attire and went through the usual nightly routine of tooth brushing and so on before getting into a comfortable bed fitted up in a darkened laboratory. A sensitive oximeter was then attached to the ear-lobe on the side opposite to that on which the person normally slept. It was linked with a device which made a continuous record of any oxygen changes in the blood flowing through the ear-lobe arteries.

An observer, usually Dr. Lovett Doust himself, kept watch all night noting changes in the sleeper's position, the effect of outside noises and how often the sleeper snored.

The results proved that there is a close connexion between the oxygen content of the blood and depth of sleep. Usually, as Fig. 2 shows, the person's blood carries almost the maximum amount of oxygen possible when he climbs into bed—unless he is excessively tired, though even then it is at least 92% saturated with the gas. Then from the moment at which the light goes out the oxygen level falls steadily to reach a minimum of about 87% saturation at the time of deepest sleep. This lowest level is usually maintained for about half an hour after which it rises progressively until awakening.

Dr. Doust was able to recognise seven 'planes' of sleep corresponding to seven levels of oxygen saturation:

Plane 1. Wakefulness, with an arterial oxygen saturation of about 96%. Conversation is possible during this stage. There may be much yawning, sighing and often coughing.

Plane 2. Pre-sleep (90–92%), in which muscular relaxation is greater and there is transitory loss of awareness with increasing mental fantasy. While passing into the next sleep-plane there is a tendency to scratch and rub the face.

Plane 3. Light sleep (89–91%). The body still responds to stimuli but for the most part unconsciously. This is characteristically a noisy period with groaning, grumbling, gasping and snoring.

Plane 4. Deep sleep (87–88%), in which the sleeper is "dead to the world".

Plane 5. Light sleep (89–91%), the first stage in the process of reawakening.

Plane 6. Pre-wakefulness (90–92%).

Plane 7. Awakening (92–98%).

The records showed that, in a person who keeps normal

hours, deepest sleep coupled with the lowest oxygen content of the blood occurs between 3 and 5 a.m. which also happens to be the time when life seems to be at its lowest ebb. Whenever a sleeper awoke with this blood-oxygen level still low—by being roused out of deep sleep for instance—it climbed back only slowly to the level consistent with consciousness—a finding which will be appreciated by those who are frequently awakened by late-night telephone calls.

A trumpeting snore often occurred when the blood had reached a particularly low level of oxygen content. Dr. Doust believes this may be a mechanism for increasing the amount of oxygen in the blood. Such snoring sometimes awakens the sleeper and may be a danger signal.

Most of the sleepers said that they preferred to sleep on a particular side, but by the time they reached the phase of deepest sleep most of them were lying on their backs.

Dr. Doust fixed the oximeter on to the ear-lobe of the side opposite to that on which they preferred to lie and asked them to avoid lying on it if possible. The fact that they all managed to carry out this instruction even during full unconsciousness is interesting, because in previous studies of sleep movements where no such request was made, turning on to both sides several times during the night was almost invariably recorded.

He found that a fall in oxygen level usually preceded a sleep movement, to be followed by a slight rise once the movement was complete.

In these experiments the sleepers were subjected to night noises of many kinds—traffic noises, the sirens of Thames tug-boats, the drone of aircraft and the cries of sick children in other wards. These seemed to be unnoticed during the phase of deepest sleep, but in the light sleep phases such noises caused a rapid rise in oxygen concentration by 2% or so. It seemed possible that this was part of the mechanism responsible for the awakening of a sleeper in response to a noise.

The lulling effect of certain noises reminiscent of the 'tiddly-dum, tiddly-dum' rhythm of a railway train was also tested. It was found that comparatively slow rhythms rapidly induced a fall in the blood-oxygen level while certain fast rhythms induced a rise.

All the main manifestations of sleep, such as lowered blood pressure, slower heart beat and lower body temperature seem to be associated with a reduced oxygen concentration in the blood, Dr. Doust reported.

Even the bizarreness of dreams may be due to that cause especially as dream-like hallucinations are common among aeroplane pilots suffering from anoxia.

Dr. Doust was careful to point out that what happens in the skin where all his measurements were made is not necessarily what happens in the brain. But he tentatively suggested that the reduction of the amount of oxygen available to the central nervous system may be a main cause of sleep.

There is no doubt that the blood-supply to the brain—and hence the overall supply of oxygen—is considerably reduced during sleep. The brain coverings (the *meninges*) which carry the nourishing blood vessels can be seen to go paler when a patient whose brain is exposed as a result of an injury, falls asleep.

A 'brain anaemia' theory of sleep is particularly attractive because it is so simple. It would explain, for instance, why we feel sleepy when we sit in front of a hot fire: the warmth makes the blood vessels of the legs expand and they fill up with blood which would otherwise have gone to the brain. The lassitude that overtakes us after a big meal seems to be explained by the consequence that when the stomach is full, blood is diverted there to help digestion. Conversely the sleep-retarding effect of hunger may be explained by the fact that so little blood is going to the digestive system that there is ample to supply the brain.

Convincing though Dr. Doust's results may seem, they do not dispel the criticisms of other scientists who maintain that these oxygen changes in the blood are *effects* of sleep and not the cause of it.

Professor Kleitman has criticised the work on the ground that the lowest levels of blood-oxygen strength in deep sleep—87%—are probably not small enough to produce

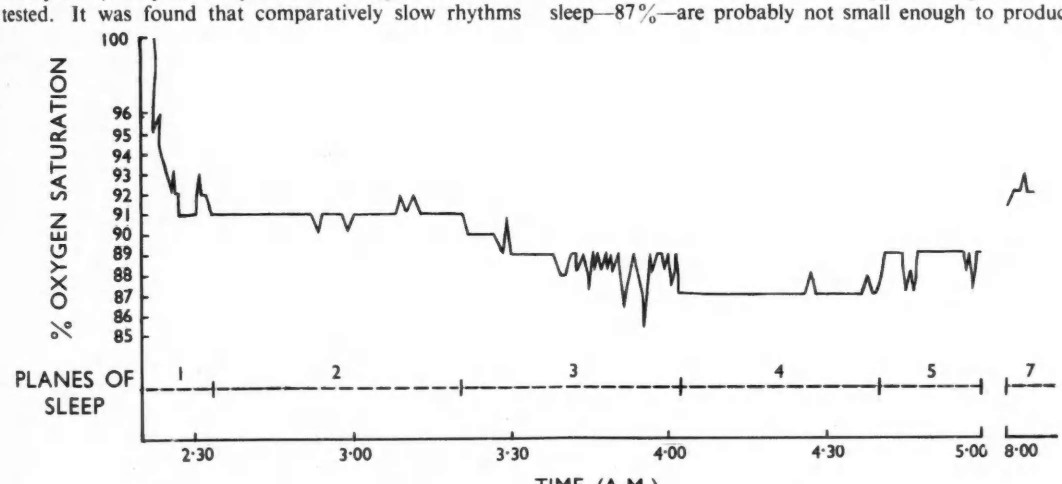


FIG. 2. Graph showing the fall and fluctuations of the blood-oxygen saturation in a healthy man during a night's sleep. The figures along the dotted line refer to the seven planes of sleep described in the text.

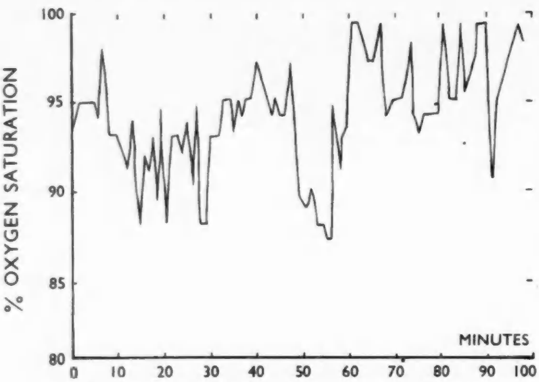


FIG. 3a. Graph of the blood-oxygen saturation of a 25-year-old neurotic man showing wild fluctuations while he was subjected to minor frustrations during a psychiatric interview.

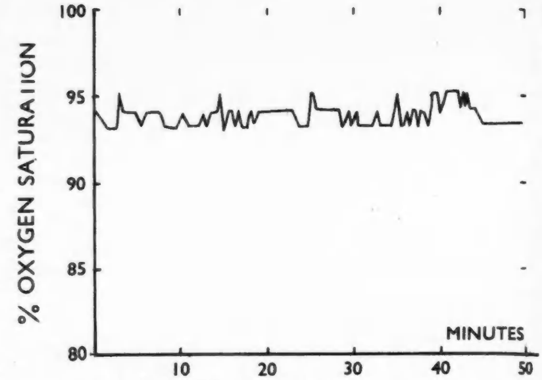


FIG. 3b. Graph of the blood-oxygen saturation of a healthy man subjected to the same type of stress for comparison with figure 3a.

any effect on mental or physical performance. A drop to 68–75% of saturation is needed to produce unconsciousness at high altitudes (18,000 ft.).

Perhaps the strongest and most obvious objection to the brain anaemia or anoxia theory is that many people can drop off to sleep at any odd moment they wish. This objection also operates against the theory that the body tissues generate some special sleep-producing substance which gradually accumulates during the day.

There may be 'fatigue products' which collect in the blood and tissues and help to make the body feel tired, and at one time physiologists thought these were directly responsible for the onset of sleep. Experiments are on record in which blood was taken from a dog which had been exhausted by continuous exercise and was transferred into a fresh dog which then developed the symptoms of sleepiness. This 'chemical' theory of sleep was convincingly disproved, however, by some observations on Siamese twins in Russia. The twins shared the same blood system, so that effects of any fatigue products should have been the same in both. Yet one would sleep while the other was wide awake.

Dr. Doust's chief interest in this sleep research was in comparing the general oxygen saturation of the blood of mental patients with that of healthy people.

He found that whereas in normal subjects the oxygen level was between 92 and 98% of saturation, in schizophrenics it was often consistently below 91%, i.e. they suffered from persistent oxygen shortage even while awake.

These findings led to the tentative suggestion that schizophrenics suffer from hallucinations because they live in a permanent 'dream state'.

The suggestion was supported by the results of experiments in which the patients were allowed to inhale oxygen to raise their oxygen-saturation levels. They became more rational and nearer normal. Thus at an oxygen strength of 93% a young man said "I am in hospital for help", while at his regular concentration of 86— he talked gibberish.

To test the reverse of this experiment a healthy 35-year-old man volunteered to breathe 'thin' air (a special mixture of oxygen and nitrogen) which lowered his oxygen strength down to the level of a schizophrenic. After five minutes he felt sleepy. Within an hour he showed schizophrenic-like symptoms in his speech and behaviour. After inhaling thin air for four hours everything seemed 'dream-like' to him.

This process of deliberately reducing the oxygen concentration of the blood proved to be of value in the diagnosis of borderline cases—patients who were suspected of schizophrenic tendencies but appeared fully rational when they presented themselves for psychiatric consultation.

When their oxygen concentration was reduced by subjecting them to a relatively slow rhythm, such as a flickering light accompanied by a tapping sound, their behaviour rapidly became symptomatic of their true mental condition.

Such a case, described by Dr. Doust in a scientific report, is one of the most extraordinary on medical record. It was the case of a 42-year-old man who was normal by day but lived the life of an 'ape man' by night, leaping from his bed while still asleep and climbing trees with astonishing agility. On reporting to the Maudsley Hospital, the man who had lived many years in India complained that at about 2 a.m. when he was still asleep he felt himself drawn away from the real world to live the life of an ape. He could never remember what happened during the next few hours, but his doctors stated that he got out of bed while still asleep, adopting the posture of an ape, and attacked anyone who tried to restrain him. If allowed to venture outside he would climb trees "with remarkable agility for a man of his age and proportions".

When Dr. Doust examined him he seemed reasonably normal, but at a lower oxygen strength of his blood he began to get hallucinations of chimpanzees and gorillas.

Tests on neurotic patients showed that the level of oxygen saturation in their blood fluctuated wildly when they were subjected to stresses such as minor frustrations (Fig. 3a).

This effect seemed to be so characteristic of the mental condition that Dr. Doust suggests that the inability of the blood to maintain a reasonably steady level of oxygen saturation is a diagnostic sign of deep-seated emotional instability. If a fluctuating level repeatedly brings the brain back to high levels of consciousness, as Fig. 3a suggests, it might also explain why neurotics have such difficulty in getting off to sleep.

ARTIFICIAL FIBRES

R. W. MONCRIEFF
B.Sc., F.R.I.C., F.T.I.

The inventor of the eyed needle was a genius, and it was he who really started the fibre business; perhaps he used hairs plucked from his own beard, or perhaps the first fibres used for sewing were stripped from the bark of trees. In the next twenty thousand years as civilisation gradually shaped itself, animals were herded and their hair was put to increasing use, the merits of flax were discovered and the rare beauty of the thread in which the silkworm envelops its cocoon was appreciated. Wool and goat hairs, linen and silk were the ancient fibres. No one knows when it was discovered that the short fibres such as those of wool could be spun into a yarn by arranging them parallel and twisting them together, nor when the art emerged of making the yarn into a fabric by interlacing a number of threads that ran in one direction with a number at right angles to them. Spinning and weaving developed in the pre-history of man; they were already well advanced in the early civilisations of the Swiss Lake Dwellers, of China, India and Egypt. The use of the seed hairs of cotton came later, but the fibres used by the ancients were still the main fibres in use a hundred years ago, and they were the only fibres that were used in considerable quantities even as recently as forty years ago. For thousands of years half a dozen fibres met our needs; yet in the last few decades, at least a dozen new fibres have come into wide use.

CONTINUOUS FILAMENTS

It should not be thought that *attempts* to make new fibres date back only a few years; on the contrary, the intrinsic beauty of real silk, coupled with its comparative scarcity and high price, long ago inspired efforts to imitate it. The fibre that the silkworm spins was continuous, whereas the other natural fibres were only a few inches long and had to be spun together to make a long thread; real silk, by virtue of its continuous filaments, possessed a lustre and sheen and smoothness to the touch that were not approached by the spun or 'staple' yarns made from flax, cotton or wool. For these reasons silk was the most prized of all the fibres. As its outstanding characteristic was the length or continuity of its fibres, it is not surprising that a great deal of effort was directed to producing man-made fibres with similarly long filaments. As early as 1665 Robert Hooke remarked that "there might be a way found out to make an artificial glutinous composition, if not fully as good, nay better, than that excrement or whatever other substance it be, out of which the silkworm wire-draws his clew". All sorts of substances were tried; glue, gelatine, starch, resins, gums and so on. The usual method was to make a glutinous solution and to squeeze it through a tiny round hole—this method is precisely that which is used today to make our rayon, but today we call the holes 'orifices' in the 'spinning jet'.

The search for a raw material for making an artificial silk ranged far and wide, but those pioneers who chose materials that were either naturally fibrous themselves or associated with natural fibres were nearest to hitting the target. One ingenious individual ground up dead silkworms to a glutinous mass and by extruding it through an orifice he made something resembling a fibre; another took the inner bark of the mulberry tree, the fibre on which the silkworm feeds, managed to dissolve it in suitable chemicals, and was able to make a thread from the resulting sticky solution.

CHARDONNET SILK

Real success was first achieved by Count Hilaire de Chardonnet in France. He it is who is generally credited with the invention of the first practicable process for making artificial silk. Chardonnet used mulberry fibres as his first raw material, but soon changed to cotton which chemically is essentially similar, and which had the outstanding advantages of being abundant and cheap. His problem was to make the cotton into a solution, and he solved this by treating it with a mixture of nitric and sulphuric acids. His product was called cellulose nitrate, and he was able to dissolve it in a mixture of alcohol and ether. This solution was squeezed through small nozzles; with the evaporation of the alcohol and ether, the resultant product was cellulose nitrate in the form of filaments. As more and more solution was squeezed through the nozzle, the more filaments grew in length and could be wound continuously on to spools. Thus was the first useful artificial silk made, and it caused a sensation when it was shown at the Paris Exhibition in 1889. This artificial silk was, however, very inflammable and far too dangerous to use in the manufacture of wearing apparel, but Chardonnet subsequently found a way of converting the cellulose nitrate back into cellulose, scarcely more inflammable than the cotton from which it originated. Sometimes, however, accidents happened, as a result of the denitration process having been only incompletely carried out, and the upshot was that the sale of Chardonnet's silk was eventually prohibited in France.

VISCOSE RAYON

The next big step forward came from the work of C. F. Cross and E. J. Bevan. Like Chardonnet, they aimed at an artificial silk. Like him they started with a naturally fibrous material, cellulose; again they dissolved the cotton (or sometimes wood pulp) fibres and squeezed the resulting solution through fine orifices to form filaments which could be wound on to spools, twisted together and afterwards woven into a textile fabric. Cross and Bevan's great contribution was that they discovered a new way of dissolving the cellulose and of 'regenerating' it; in effect, they dissolved the short cotton fibres and extruded the solution so that continuous filaments of unlimited length were formed.

Their fibre was an example of *regenerated* fibre; the term is applied where the natural fibrous material has been dissolved and then regenerated, by some chemical means, from the solution. Viscose rayon, cuprammonium rayon, Ardil and Vicara are all regenerated fibres.

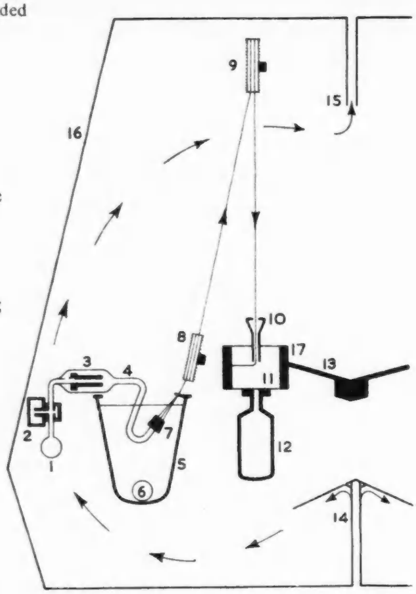


FIG. 1. Spinning viscose rayon. This schematic diagram shows the essential units in one half of a double-sided spinning machine.

1. Section of main viscose feed.
2. Pump.
3. Candle filter.
4. Glass rounder end.
5. Coagulating bath.
6. Section of acid replenishing pipe.
7. Spinneret.
8. Bottom godet.
9. Top godet.
10. Funnel.
11. Topham Box.
12. Drive for Topham Box.
13. Traverse.
14. Fresh air inlet.
15. Fumes sucked out.
16. Sliding windows.
17. Cake.

The chemical process that Cross and Bevan used—the 'viscose process'—has proved to be far and away the simplest and cheapest process for making rayon. Most of the rayon produced today is made by this process.

The modern 'viscose' process consists essentially of the following steps:

1. Timber (usually spruce) is chipped up (after removal of the bark) and treated with calcium bisulphite and superheated steam to convert it to pulp. The pulp is bleached, dried and pressed into boards, a convenient form in which to transport it to the rayon factory.
2. The pulp boards are steeped in a concentrated solution of caustic soda; this swells the boards which are then shredded into 'crumbs' and 'aged' for a few days.
3. The 'soda cellulose' is reacted in large churns with carbon disulphide. (This reaction was the essential feature of Cross and Bevan's discovery.)
4. The product from the reaction of the soda cellulose and the carbon disulphide is known as *sodium cellulose xanthate*. It is dissolved in dilute caustic soda to give a solution which is known as 'viscose'. This solution cannot be spun whilst it is still 'young', but has to be left to ripen for a few days.
5. The viscose solution is filtered, and freed from included air bubbles (which would interrupt the spinning).
6. The viscose solution is pumped through fine orifices into a solution of sulphuric acid and sodium sulphate. As soon as the sodium cellulose xanthate of the viscose solution meets the sulphuric acid, it is chemically changed to cellulose. Whilst the cellulose is being regenerated in the spinning bath it forms a filament which is wound up. The general arrangement of a viscose spinning unit is shown in Fig. 1.

Until fairly recently viscose rayon was wound in a Topham box; this consisted of a pan into which the filaments were fed; the pan rotated rapidly and the filaments were therefore thrown against the side of the pan, where they built up to form a 'cake'. The yarn in cake form was then washed, purified, bleached, dried and wound on to cones or bobbins for use in the traditional textile operations of winding, knitting and weaving. More recently, a 'continuous' method of spinning viscose rayon has been introduced in which the yarn is washed and dried as fast as it is spun, and is then wound directly on to a bobbin.

Viscose rayon has revolutionised women's wear. Rayon frocks, two-piece sets and nightdresses which would have been the envy of a queen in an earlier age, are commonplaces to the working girl.

It was not until the twenties that viscose rayon was widely used, but by 1940 there was more rayon than wool used in the world. Such has been the stupendous success of this rather slow starter—viscose rayon.

CUPRAMMONIUM AND ACETATE RAYON

Cuprammonium rayon is very similar to viscose rayon; it also is a regenerated cellulose, but the cuprammonium process yields filaments which are often finer than are those of viscose. This kind of rayon is made by dissolving purified cotton or wood pulp in a 'cuprammonium' solution, which is prepared by dissolving basic copper carbonate in ammonia. The resulting cellulose solution is extruded through orifices into water; the cellulose is thus precipitated in the form of filaments.

The orifices that are used for cuprammonium spinning are fairly large, perhaps half a millimetre in diameter (eight times wider than the average viscose spinning orifice) so that the cuprammonium filaments as they are spun are coarse; they are, however, subjected to such a high degree of stretch immediately after having been spun that the final filaments are even finer than viscose rayon.

'Bemberg' rayon is made by a cuprammonium process.

Chardonnet's silk, viscose rayon and cuprammonium rayon all consist of natural cellulose that has been dissolved and regenerated in the form of long continuous filaments which have a lustre justifying the name 'artificial silk'. The product is very different in physical form and appearance from the starting material, but chemically it is the same; it is nothing but cellulose.

Cellulose acetate is also made from cellulose, but differs from the other fibres that have been discussed in this respect: one of the chemical changes that the cellulose has undergone during processing is allowed to persist even after the artificial filaments have been made. The final product, the rayon, consists not of cellulose but of cellulose acetate. Whereas Chardonnet's cellulose nitrate was very inflammable and had to be denitrated, cellulose acetate is rather

less inflammable than cotton, so that no necessity for the removal of the acetate groups arises.

The raw material in the acetate process consists of cotton linters, those very short cotton hairs which are retained by the cotton seed when the long hairs are removed in the 'ginning' of cotton.

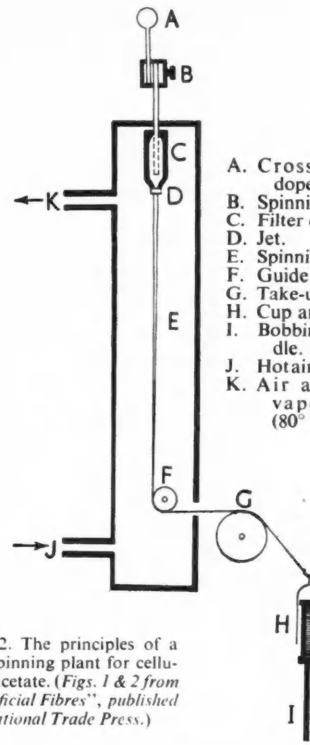
The cotton linters are steeped in glacial acetic acid to make the cellulose more reactive. Then follows *acetylation*, which is brought about by treatment with a mixture of acetic anhydride and glacial acetic acid; the presence of a little sulphuric acid promotes the reaction catalytically. After a day or so all the cotton fibres have been converted into soluble cellulose triacetate—usually known as the 'primary' acetate.

The primary acetate is then allowed to stand in a dilute acetic acid solution which converts it to the 'secondary' acetate which is soluble in acetone, whereas the primary acetate is not. An acetone solution is now prepared, and if a yarn with a subdued lustre is wanted, a pigment such as titanium dioxide is added at this stage. The solution is pumped through a spinnerette into a cabinet of warm air. The acetone evaporates, and filaments of cellulose acetate are left, to be immediately twisted into a yarn which is wound on a bobbin. The general arrangement of a cellulose acetate spinning unit is shown in Fig. 2.

Whereas the viscose and cuprammonium rayon processes are known as 'wet spinning', because the spinning solution is extruded into a watery solution, the spinning process for cellulose acetate fibre is known as 'dry spinning' because no wet coagulating bath is used. (Chardonnet's artificial silk was also dry-spun.)

Yarn made from cellulose acetate is attractive to the touch and also drapes well; it is widely used for lingerie and dress fabrics. ('Celanese' is a typical acetate rayon.)

This kind of rayon was introduced in the early twenties, and by 1928 its production was already considerable. It has, however, never been made in such large quantities as viscose rayon, nor is it likely to be as it costs more to produce than viscose rayon.



A. Cross-section of dope line.
B. Spinning pump.
C. Filter candle.
D. Jet.
E. Spinning cabinet.
F. Guide roller.
G. Take-up roller.
H. Cup and bobbin.
I. Bobbin driving spindle.
J. Hot air inlet (100° C.)
K. Air and acetone vapour outlet (80° C.).

FIG. 2. The principles of a dry spinning plant for cellulose acetate. (*Figs. 1 & 2 from "Artificial Fibres", published by National Trade Press.*)

ALGINATE FIBRES AND ARDIL

Cellulose is the main constituent of all land plants, but its place is taken by other substances in the brown seaweeds. They contain a high percentage of alginic acid, which chemically is more closely related to the pectins of fruits than to cellulose. Alginic acid is nowadays extracted from seaweed in several parts of the world, but only in Britain is it converted to a fibre.

Treatment with caustic soda converts the acid into a solution of sodium alginate, which is then extruded through a spinning jet into an acidified solution of calcium chloride. The sodium alginate reacts with the calcium chloride to form calcium alginate which is insoluble and can be wound up in filament form.

Calcium alginate fibres are so susceptible to weak alkali that they cannot be safely washed with some soaps and modern detergents. Oddly enough, however, this very solubility in weak alkali is the basis of a variety of special uses for calcium alginate fibre. It has been used as a 'scaffolding' thread which eventually disappears. It is, for example, not practicable to make a wool fabric so gossamer-light that it can be made into glamorous nightdresses; the very fine wool yarns which would have to be used could not withstand the weaving operation. It is, however, possible to twist the light wool yarns with heavy calcium alginate threads and then weave this twisted or doubled yarn; the fabric so made is heavy, but when treated in dilute alkali all the calcium alginate threads in the fabric dissolve, leaving a gossamer-like fabric of wool.

In the search for raw materials for artificial fibres, proteins have by no means been overlooked. Wool has some of the most highly prized properties of all natural fibres and a great deal of effort has been put into attempts to dissolve wool and regenerate it in the form of continuous filaments. These attempts have never been very successful because of the impossibility of dissolving wool without breaking down its molecular structure.

But wool is a protein, and there are plenty of other proteins which, as a class, are chemically similar amongst themselves but are distinct from cellulose and alginates. One such protein, the one that occurs in groundnuts or 'monkey-nuts', has been used to make the fibre known as 'Ardil'. This fibre, because of its protein character, is warm and soft to the touch, like wool. Because it is much cheaper than wool, it is used to dilute wool. Pullovers, jumpers, etc., made from a 50/50 mixture of Ardil and wool are indistinguishable, except to the expert, from all-wool garments.

(To be concluded.)

Far and Near

Night Sky in April

The Moon.—New moon takes place on April 13d 20h 09m, U.T. and full moon on April 29d 04h 20m. The following conjunctions with the moon take place:

April			
1d 01h	Saturn in conjunction with the moon	Saturn	8° N.
12d 02h	Mercury ,,	Mercury	6° S.
15d 16h	Mars ,,	Mars	5° S.
16d 02h	Jupiter ,,	Jupiter	6° S.
28d 04h	Saturn ,,	Saturn	8° N.

In addition to these conjunctions with the moon, Mars is in conjunction with Jupiter on April 27d 16h, Mars 1·1° N., and Mercury is in conjunction with Venus on April 27d 21h, Mercury 7·2° S.

The Planets.—Mercury is too close to the sun throughout April for favourable observation. Venus sets at 20h 40m on April 1, which is more than two hours after sunset and is conspicuous in the western sky. The planet is in inferior conjunction on April 13 after which it becomes a morning star but is not easily observed until near the end of the month; on April 30 it rises an hour before the sun and is visible for a short time in the eastern sky. Mars sets at 21h throughout April and can be seen for some time after sunset. About the middle of the month it lies a little south of δ Arietis and at the end of the month about 4° south of the Pleiades. Jupiter sets at 22h 10m, 21h 35m and 20h 55m on April 1, 15 and 30, respectively. Its proximity to Mars is noticeable and attention has already been drawn to the conjunction between the two planets on April 27. Saturn rises at 19h 35m, 18h 30m and 17h 25m on April 1, 15 and 30, respectively, and remains visible until the morning hours. It is in opposition on April 14, that is, the earth, the sun and Saturn are nearly in a line, so that the planet rises about the time of sunset and sets about the time of sunrise. It is easy to recognise the planet by its beautiful ring system which can be seen with a pair of binoculars on quite a small telescope. During the month it lies a little north of Spica, the brightest star in the constellation of Virgo.

Scientific Advice on Soil Blocks

The technique of making soil blocks, which makes it possible for the gardener and nurseryman to disperse with the use of clay pots, brings advantages in certain circumstances. A scientific investigation of the method has been made, and the factors which determine its success in practice have been established. A report summarising these details is now available as John Innes Leaflet No. 12 ("Soil Blocks"), published by Oliver and Boyd of Edinburgh, price 9*d*.

"Discovery" Article wins R.I.C. Prize

The Radio Industry Council awards premiums each year for well-written articles dealing with radio and electronic developments. This year a premium of 25 guineas has been given to Mr. W. R. Stamp, for his account of underwater television published in the September 1952 issue of DISCOVERY.

"Endeavour" Prizes

The subjects for this year's "Endeavour" competition for scientific essays are as follows:

1. RADIO-ASTRONOMY
2. COLOUR AND CHEMISTRY
3. BIOLOGY IN WORLD AFFAIRS
4. SCIENCE AND SAFETY IN TRANSPORT
5. SCIENCE AND ART
6. SCIENTIFIC CONTRIBUTION TO MEDICINE
7. SCIENTIFIC SOCIETIES AND THEIR ROLE
8. POWER AND CIVILISATION

There are three main prizes, of 50, 25 and 15 guineas respectively, and two special prizes of 5 guineas for competitors under 18. The closing date for the competition (which is open to persons not older than 25) is June 1. Full particulars may be obtained from: The Assistant Secretary, British Association for the Advancement of Science, Burlington House, Piccadilly, London, W.1.

Australia and Artificial Rain-making

No country has advanced as far as Australia in experiments for artificial rain-making, according to Mr. Casey, the Minister responsible for the Commonwealth Scientific and Industrial Research Organisation, the dominion's counterpart of our DSIR. Three CSIRO experts connected with this work, including Dr. E. G. Bowen, have just visited the U.S.A. to exchange information on this subject. Mr. Casey also stated that there was still a long way to go before rain could be made to fall just when and where it was wanted, and it was possible that this desirable point would never be reached. If the present experiments did succeed, no country would benefit more than Australia.

The rain-making investigations are conducted by the Radiophysics Laboratory of the CSIRO, which is quartered in the grounds of Sydney University. In its studies of cloud and rain physics this unit has made great use of radar techniques, which make it possible to follow the events which occur inside rain clouds after they have been 'seeded' with dry ice or silver iodide.

The Royal Military College of Science

The Army's scientific educational establishment, which was described by Major Banner in our February 1953 issue, has now, with the Queen's consent, been given the title of "The Royal Military College of Science".

Directing the Movement of Fish by Electricity

At a recent meeting of the Royal Society of Edinburgh, Mr. Norman G. Lethlean, research engineer of the North Scotland Hydro-Electric Board, described how electricity was being used at Morar to guide salmon into the fish passes (which are provided so that fish by-pass the dam in their movements up and downstream). A row of underwater aluminium electrodes about 14 feet long extend to within 3 inches of the tailrace channel, and two other electrodes 16 feet apart are placed farther downstream. When a pulsating current is passed across the electrodes, the fish respond by veering away and are so guided into the fish pass.

Within the pass the fish are counted by means of an electrical bridge counter in which one set of units count the mature salmon travelling upstream and another set the descending offspring. A nearly 100% efficiency in guiding the fish is claimed.

The Wellcome Foundation's New Chairman

Mr. M. W. Perrin has left the Head Office Research Department of I.C.I. to become chairman of the Wellcome Foundation. During the war he joined the British atomic energy project under DSIR, and was Sir Wallace Akers's principal assistant. Later the project was put under the Ministry of Supply, and Mr. Perrin became Deputy Controller (Technical Policy) in that department's Division of Atomic Energy. Pre-war he was in charge of the high-pressure section of I.C.I.'s Research Department at Winnington, which discovered polythene.

Rumford's Bicentenary

The bicentenary of the birth of Benjamin Thompson, Count Rumford, on March 26, 1753, was celebrated by the American Academy of Arts and Sciences last month. Rumford Medals of the Academy were presented to Profs. E. Fermi, W. E. Lamb, jun. and L. Onsager. A number of lectures were given by distinguished scientists, including Sir Alfred Egerton of Imperial College and Prof. F. E. Simon of Oxford.

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In London a lecture about Rumford's scientific work was delivered on March 27 by Prof. C. K. Rideal, who was for a while director of the Royal Institution which Rumford founded.

Dr. Darlington Leaving John Innes

Dr. C. D. Darlington is relinquishing the directorship of the John Innes Horticultural Institution, of which he has been head since 1939, and will succeed Prof. T. G. B. Osborn as Sherardian Professor

of Botany at Oxford. Dr. Darlington, who has frequently contributed to DISCOVERY, joined John Innes in 1923, after graduating at Wye College. In 1946, and only five years after he was elected an F.R.S., he was awarded the Royal Medal of the Royal Society. His books include *Recent Advances in Cytology* and *The Evolution of Genetic Systems*, the latter epitomising the originality of the ideas which he has contributed to cytological and genetical theory.

Prof. Oliphant and Australia's National University

Prof. M. L. E. Oliphant has become Acting Vice-Chancellor of the Australian National University at Canberra. Prof. Oliphant left Birmingham University soon after the war to direct the Research School of Physical Sciences in the National University.

No Shortage of ACTH

ACTH has been scarce in Britain, and much of the drug used by British doctors has been supplied by the U.S.A. First ACTH to be produced in Britain was prepared from pig pituitary glands, the firm concerned being Organon Laboratories Ltd. Now the first plant in the world to make ACTH from ox pituitaries has been brought into operation by Crookes Laboratories at Park Royal, and this hormone preparation is said to be in every way as effective as that derived from pig pituitaries.

ACTH production is now capable of meeting the maximum home demand that could be visualised, and there should be a surplus for export.

U.S. Services Collaborate in A-bomb Tests

The latest series of A-bomb tests which started last month at the Nevada proving ground has been planned to include at least ten atomic explosions. Over 20,000 Servicemen from the U.S. Army, Navy and Air Force have been taking part.

Infra-red microscopy and the Image-converter Tube

The infra-red telescope involving the use of an image-converter tube was developed considerably during the war in connexion with the telescopic sights used on special snipers' rifles. Image-converter tubes can also be applied to microscopy, and the February 1953 issue of *The Journal of the Quekett Microscopical Club* contains a description by B. K. Johnson of Imperial College of an apparatus he has developed which is valuable for the microscopic examination of opaque objects in the 8000–20,000 Ångström region. The paper is illustrated with photomicrographs obtained with this apparatus, showing how details in a beetle wing, for example, which were invisible through an ordinary microscope, showed up clearly when photographed using 12,000 A illumination.

A-Bomb Expert to give Reith Lectures

The B.B.C. announces that the Reith lectures this year will be given for the first time by an American—Professor J. Robert Oppenheimer, director of the Institute for Advanced Study, Princeton University, New Jersey. Professor Oppenheimer has chosen as his subject "Science and contemporary man". During the war he was a key figure in the U.S. atomic bomb project, and was in charge of the Los Alamos Laboratory which looked after the research, development and testing behind the construction of the first A-bombs.

NAMING BRITISH WILD FLOWERS

It is a welcome feature of the times that so many people are interested in wild plants. All of these wish to know the names of the plants they find, and some wish to use those names as a foundation for further study of the plants. Approximate naming is not difficult if suitable books are used, though plants with small flowers, or plants which differ only slightly from their close relatives may be awkward to name unless some knowledge of formal botany has been obtained; that knowledge is readily gained from the books. Amateurs will be well advised to learn and use the Latin names of the plants, for these names have a precise meaning, whereas popular names not only vary from place to place, but may belong to several distinct kinds of plants. In theory, there is but one Latin name for each kind of plant; in fact, this is not yet true, for international agreement has not been reached on the use of the Latin names. However, a Latin name learned from a reliable book may be safely used, for it will have a precise meaning. The amateur botanist in this country cannot do better than use the names given in *Flora of the British Isles* by Clapham, Tutin and Warburg.

Naming plants with the aid of a book must be done from the *descriptions;* it is unwise to name from pictures alone. Pictures are most useful in preliminary attempts to find a name, and they are equally useful in checking the results of naming from descriptions, but the descriptions are the final authority. All the better books on British plants include short keys, the intention of the authors being that the keys will lead the reader conveniently to the name which is being sought. With a little practice, names may be found with the aid of keys, but keys are traps for the inexperienced. It is easy to go astray, and one faulty step means that a fresh start has to be made. A name found by the use of a key is not to be accepted until the specimen has been examined thoroughly and compared point by point with the description, which it must match in all significant respects.

Most amateurs will probably not intend to publish accounts of the plants they find. Should publication be contemplated, then accurate naming becomes of the greatest importance, and a professional botanist should be consulted; he will confirm the name, or show the amateur how to do that.

Most books on British wild plants are concerned only with those plants which are regarded as natives. That may be taken to mean that the plants live and maintain themselves as members of the wild population. We know that some of our common wild plants were introduced from abroad in past times, but have become established here; those plants are described in the floras, and they give no trouble in naming. But there are many recent introductions, usually not described in the British floras, and these may plague the amateur. Some have a precarious footing, occur chiefly near docks, and probably persist only because fresh seeds are thrown out from time to time in rubbish from abroad. Others are steadily spreading and maintaining themselves from seed produced on the spot. A large number of these immigrants can be named from Clapham, Tutin and Warburg as well as a goodly selection of kinds which have been planted, and seem to be wild.

Some books are listed below; would-be purchasers will do well to consult a bookseller for details of price and availability.

Clapham, A. R., Tutin, T. G., and Warburg, E. F., *Flora of the British Isles*; Cambridge University Press, 1952. A good, modern book, which seems likely to be the standard work for years to come. A set of illustrations is expected to become available before long.

Bentham, G. and Hooker, J. D., *Handbook of the British Flora*, and its companion volumes, *Illustrations of the British Flora*, by W. H. Fitch and W. G. Smith, and *Further Illustrations of British Plants*, by R. W. Butcher and F. E. Strudwick; published by L. Reeve & Co., Ashford, Kent. These three volumes cover the British vascular plants, and are very straightforward in use.

Babington, C. C., *Manual of British Botany*; Gurney & Jackson. An accurate book, but not always easy to use. Like the preceding books, it gives little information about introductions and escapes from cultivation.

Watts, W. M., *A School Flora*. Longmans, Green & Co. A simple book, easy to use, but not wholly comprehensive.

Skene, Macgregor, *A Flower Book for the Pocket*; Oxford University Press. A simple book which describes many wild flowering plants, but not all. It has numerous coloured illustrations which, in the latest edition, have been improved by printing from a new set of plates.

Bonnier, G., *British Flora* (translated and adapted by E. Mellor); J. M. Dent & Sons. A very convenient book consisting largely of keys illustrated by over 2000 small drawings. It covers British vascular plants and a number of cultivated plants. Naming from this book should be confirmed by using another book in which there are more detailed descriptions.

Ross-Craig, Stella, *Drawings of British Plants*; G. Bell & Sons. This is a series of excellent line-drawings of the plants. So far, six parts have been issued, containing 291 plates; the whole work is expected to contain between 1500 and 1800 plates.

B. BARNES

THE BOOKSHELF

Radio and Radar Techniques by A. T. Starr (*London, Pitman, 538 pp. + 280 pp. of appendices, 1953, 75s.*)

This is an immense and authoritative volume. The size of the appendices containing the mathematical analyses, amounting to more than a third of the size of the whole book, is sufficient evidence of this. Every chapter has its bibliography. The 800 pages are printed in small, though clear and readable, type, so that, on a very rough estimate, there must be about half a million words and symbols.

The author, Dr. A. T. Starr, is very experienced at high-level exposition, and everything he writes is good. In order to keep the size of the book down to its already great bulk he has sacrificed altogether any applications of the methods and techniques he expounds. This procedure can lead to difficulties of over-compression, but as the level is specialist and post-graduate, the reader who the book is intended for will be unlikely to complain at the result in this instance.

Dr. Starr's aim is to cover the essentials of the radio and electronic field in one volume, a task not before attempted at such a high level. The book will certainly become the standard work.

Finally, it should be noted that if there is no printing error in such a wealth of words and symbols, the publisher and author will have achieved something unique in technical publishing. But knowing the author, this reviewer should not be surprised if they have.

Astronomy for Everyman edited by Dr. Martin Davidson (*London, J. M. Dent; New York, E. P. Dutton & Co., 1953, 494 pp., 18s.*)

The years of war-time blackout resulted in a marked growth of interest in astronomy; the British Astronomical Association grew rapidly, and books on descriptive and elementary astronomy acquired a new popularity. Publishers have been quick to supply this increased demand and have provided works of almost every standard—except, perhaps, one for the amateur observer with a small telescope. Dr. Davidson and his collaborators have corrected this omission and the publishers are to be congratulated on providing so much information in such an attractive manner for a reasonable price—this is extraordinarily good value.

In reading the book one is reminded of that grand old work, *Splendour of the Heavens*, long out of print and difficult to obtain. As in the earlier work, the treatment is almost completely non-mathematical, while diagrams and drawings are plentiful; it is not, however, a book for the complete beginner, but for those who already know their way about the sky and have read at least one introductory work. The contributors, most of whom are, or have been, directors of observing sections of the British Astronomical Association, write mainly for the intending observer and provide the excellent guidance and advice one would expect. The different sections vary considerably in style and presentation, but they all share the same great enthusiasm and deep knowledge of their subjects. In a book so practical in outlook it is unfortunate that the section on instruments should contain so little of value to readers of limited means wishing to make or acquire telescopes. A sketch of a simple stand for a small instrument would be of more value than the pictures of the Sheepshanks and polar telescopes. This, however, seems to be the only serious blemish, and the book can be recommended to all whose interest in astronomy is not solely 'armchair'; they will find continuing use for it as a book of reference—for school libraries and B.A.A. members it seems to be too good to be missed.

Tables of up-to-date data about the planets and their satellites, and extensive bibliographies are included; the most modern views on planetary constitution receive attention, and the book concludes with a short section on the prospects of inter-planetary travel. G. F. WEST

Zoogeography of the Sea by Sven Ekman (*London, Sidgwick & Jackson, 1953, 417 pp., 42s.*)

This is an important work of reference, although hardly easy reading for the general naturalist. It represents a translation, with some enlargement which brings it more up to date, of Professor Ekman's *Tiergeographie des Meeres*, originally published in Leipzig in 1935. The translation is certainly very welcome, making the book available to a wider circle of readers in English-speaking countries. The potential reader should, however, understand that this is *not* a work on ecology and that no descriptions will be found of the habits of marine animals in the various latitudes and depths of the oceans. Professor Ekman makes broad division of this fauna into the bottom population of the continental shelf and of the deep sea on the one hand, and on the other the pelagic fauna of the upper and of the deeper layers of the water.

He then has the problem, no easy one, of determining the horizontal subdivisions of these faunas—warm-water, temperate or polar—and this is primarily connected with temperature and so is by no means exclusively determined by latitude. Warm currents may penetrate into polar waters, as does the North Atlantic Drift, while cold waters, such as those of the Labrador Current, may extend Arctic conditions towards the tropics.

Professor Ekman has to rely for his data on collections made by marine expeditions, in particular those dealing with fishes and with echinoderms (starfishes, sea-urchins, sea-lilies, sea-cucumbers), the two big groups that have been most thoroughly studied. Interesting general conclusions do emerge from his survey, for example the conclusion that the great depths of the central Pacific are a greater barrier to distribution of the shelf fauna than is the isthmus of Panama. There was formerly connexion here between the shelf faunas of the Atlantic and Pacific. The fauna of the great ocean depths is restricted by the presence of submarine elevations, and so on.

The subject as it is presented by Professor Ekman will probably interest geographers and palaeontologists more than it will zoologists interested in living animals. This is not a criticism but a statement of the clear aims of the author.

C. M. YONGE

The Darbys of Coalbrookdale. Dynasty of Iron Founders by Arthur Raistrick (*London, Longmans, Green & Co., 1953, 308 pp., 30s.*)

Before the Industrial Revolution could get into its stride a nexus of interlocking technological developments had to be completed. Those advances in technology make a fascinating subject for historical study, a subject which can be approached from several different directions. But the general historian, the economic historian and the technological historian are all bound to focus attention on the British progress in the realm of iron smelting and the subsequent manipulation of that metal, for this was a decisive factor for Britain's entry into the new industrial era ahead of other nations. Books by all three types of historian almost invariably mention the ironworks of the Darbys of Coalbrookdale, for this was one of the pioneering centres of the iron industry. It was Abraham Darby, the founder of the firm, who effected the change-over from charcoal to coke for smelting iron ore. Other pioneering achievements to the credit of the same enterprise were substitution of iron for brass in the cylinders of the first steam-engines, the introduction of tram rails made of cast iron, and the building of the first cast iron bridge in the world. (The bridge exists crossing the River Severn near Coalbrookdale—the exact locality took its name from this technological feature and is called Ironbridge.) This book is the history of the Darbys and the Coalbrookdale works for the past 250 years. It is a painstaking work, and contains a good deal of hitherto unpublished material which makes it indispensable to anyone who needs details about those early technological developments for which Coalbrookdale is famous. Dr. Raistrick, who in 1950 published *Quakers in Science and Industry*, also gives some interesting facts about the Darbys and their connexions with other important Quaker families engaged in industry, trade and banking.

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M. YONGE

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